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Oak Ridge Associated  
Universities

Prepared for  
Division of Fuel  
Cycle and  
Material Safety

U.S. Nuclear  
Regulatory  
Commission

**ENVIRONMENTAL SURVEY  
OF THE  
SAFETY LIGHT CORPORATION  
BLOOMSBURG, PENNSYLVANIA**

**J. D. BERGER**

Radiological Site Assessment Program  
Manpower Education, Research, and Training Division

FINAL REPORT

July 1982

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J.D. Berger

Project Staff

R.D. Condra	D.A. Grove
G.R. Foltz	B.P. Rocco
R.C. Gentry	T.J. Sowell
R.C. Gosslee	C.F. Weaver

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ENVIRONMENTAL SURVEY  
OF THE  
SAFETY LIGHT CORPORATION  
BLOOMSBURG, PENNSYLVANIA

INTRODUCTION

Facilities licensed by the Nuclear Regulatory Commission (NRC) to conduct operations involving radioactive materials must ensure that personnel exposures and releases of radioactive substances to the environment as a result of their activities are within the established radiation protection guidelines. To meet this requirement, the facilities develop and conduct programs for controlling and monitoring radiation and radioactivity levels. Such programs are periodically reviewed by the NRC as part of the continuing regulatory and inspection process.

With only a few exceptions, the licensee's data regarding the monitoring program is accepted as complete and accurate. For further evaluation of data, the NRC has contracted with Oak Ridge Associated Universities (ORAU), Oak Ridge, Tennessee, to perform independent environmental radiation surveys at selected facilities. The findings are used to verify the accuracy of measurements routinely performed by the licensee and to evaluate the adequacy of the environmental control and monitoring program.

During the periods of June 8-12 and August 24-28, 1981, members of the Radiological Site Assessment Program of ORAU conducted such a survey of the Safety Light Corporation (SLC) in Bloomsburg, Pennsylvania.

## SITE DESCRIPTION

### General

Safety Light Corporation is located approximately 5 km east/northeast of Bloomsburg, Pennsylvania, on the site of the U.S. Radium facility (Figure 1). The entire U.S. Radium site occupies about 4 hectares and is bounded on the north by Old Berwick Road and on the south by the Susquehanna River. Safety Light Corporation activities occupy approximately 0.6 hectares on the eastern portion of the site (Figure 2) enclosed by a security fence. Manufacturing processes are conducted in two buildings; a third building houses radioactive waste handling and storage. In addition to the facilities presently being used by SLC for radioactive material processing, there are several small areas previously used by U.S. Radium for on-site storage or burials of low-level radioactive wastes; these areas are fenced or posted. Two small ponds, known as the East and West Lagoons, were previously used for collection of non-radioactive liquid waste from U.S. Radium operations.

### Operations

Safety Light Corporation is licensed by the NRC to use tritium in the production of luminous signs and dials, paints, gas chromatograph foils, and accelerator targets. Although only tritium has been used in the SLC facilities, most of the buildings on the U.S. Radium site have been previously used for radioactive-materials work. U.S. Radium operations during the 1950s and 1960s employed Ra-226, Sr-90, Pm-147, Tl-204, Ni-63, Cs-137, and Kr-85 for production of luminous products and foils. Some wastes from these operations were disposed of by on-site burial. The majority of these wastes has been removed, but small portions containing Ra-226, Cs-137, and Sr-90 still remain. The buildings have been decontaminated and are now used for the fabrication of non-radioactive products.

*tritiated for k etc.*



## Effluents

### Airborne

Operations involving possible airborne releases are performed under exhaust ventilation. Molecular sieve cartridges are used at the operation for treatment of gas streams with potentially high concentrations of tritium. All building exhausts are combined for discharge through a single stack, 0.6 m in diameter and 18 m high. Continuous stack monitoring for particulate, aqueous and gaseous forms of tritium is performed using filters, water bubblers, and an ionization chamber, respectively. (Following the ORAU surveys the water bubblers and ionization chamber were replaced with ethylene glycol bubblers and an oxidizer furnace/ethylene glycol bubbler respectively.) The licensee has determined diffusion factors for the exhaust stream under predominant meteorological conditions (wind toward the southeast) and utilizes this diffusion to meet the concentration guidelines for release to unrestricted areas. Monitoring for aqueous tritium is also performed at several locations along the eastern SLC facility boundary and at two private residences, located approximately 0.3 km east and 0.3 km northeast of the SLC exhaust stack.

### Liquids

With the exception of sanitary sewage, all SLC facility liquid waste products are collected in hold-up tanks. These liquids are monitored, and the dilution needed to satisfy the average annual concentration limit for unrestricted areas is determined. The diluted effluents are discharged into the Susquehanna River. Average daily flow in the Susquehanna River is  $7.5 \times 10^6$  liters. Sanitary sewage is processed in an on-site septic tank system. Storm drains from the U.S. Radium property discharge into the river.

Twenty-three sampling wells have been installed for monitoring concentrations of tritium and previously used radionuclides in the groundwater (Figure 3). SLC also performs routine monitoring of several private wells and ponds in the vicinity of the facility. Groundwater levels range from 4-8 m (1-3 m at some locations near the river) with southerly movement toward the Susquehanna River.

## SURVEY PROCEDURES

### Objectives

The objectives of this survey were to:

1. measure direct radiation levels in unrestricted areas around the entire U.S. Radium factory;
2. monitor routine releases of tritium in stack air and liquid effluents from SLC activities; and
3. measure levels of radionuclides in the environment as a result of present and previous operations of SLC and U.S. Radium.

The data obtained would be used to confirm measurements performed by the licensee, to evaluate the adequacy and accuracy of present environmental controls and monitoring procedures, and to determine if environmental contamination may be occurring as a result of past site operations.

### Measurement of Direct Radiation

Gamma radiation exposure rates at the ground surface and 1 m above the ground were systematically measured at approximately 30 m intervals around the perimeter of the U.S. Radium site. Additional exposure rate measurements were performed in the vicinity of previous waste burial and storage activities and along the drainage ditch from the lagoon area to the river. These measurements were conducted with a NaI(Tl) scintillation detector and ratemeter. Count rates were converted to exposure rates ( $\mu\text{R/h}$ ) using factors determined by cross calibration of the detector with a pressurized ionization chamber.

Beta-gamma surface measurements were also performed at the locations of the systematic gamma measurements using a G-M detector. Measurements were made with both the open- and closed-shield configuration to determine if a significant beta component was present.

### Stack Effluent Monitoring

The single stack, containing exhaust from all operations, was sampled for tritium concentrations. Approximately 6 m (10 duct diameters) downstream of the point where the fan discharge enters the stack, two holes were drilled in the duct. To determine the isokinetic sampling rate, stack velocities were measured using a pitot tube and a swinging vane anemometer. Eight measurements were made along a traverse at each access hole. Figure 4 summarizes the criteria for selection of measurement points.

Sampling nozzles were selected to provide isokinetic sampling at a rate of approximately 10 l/min. The nozzles were attached to probes, inserted in the stack, and supported by metal plates secured in position on the stack by flexible straps. Two sampling locations in the stack were selected for positioning of the stack sampling

probes. These two locations represent 1) the midpoint between the circular line dividing the cross-sectional area into two equal parts and the centroid, and 2) the midpoint between this dividing line and the outside duct wall. Sampling location criteria also required that the air flow pattern at selected points was relatively constant over distances of at least several centimeters. The exact sampling rate to achieve isokinetic sampling was calculated to be 10.2 l/min for each of the probe assemblies.

The sample collecting media consisted of 47 mm diameter membrane particulate filters (0.8  $\mu$ m pore size); a two-stage trap, containing 4A molecular sieve to remove tritium in the form of water vapor; an oxidizer furnace containing palladium sponge catalyst for converting gaseous tritium to water vapor; and a final molecular sieve trap. Filters were attached to each of the stack probes. Following removal of particulates, the air streams from the probes were combined. The sample stream was then split to provide a 1 l/min flow rate through the two-stage sieve trap, oxidizer furnace, and final sieve trap. Vacuum was provided by an 85 l/min capacity pump. Flow rates were controlled by needle valves and monitored using rotameters (0-30 and 0-4.5 l/min ranges). A photograph of the stack probe and filter holder assembly is shown in Figure 5 and a diagram of the sampling "train" is shown in Figure 6.

After installation of the probe assemblies and connection of the vacuum, control, and measurement equipment, air flows were adjusted to the desired sampling rate. Times and flow rates were noted. Samples were collected over a 24-hour period. Several checks of flow rate were made during this period to assure that the desired flows were being maintained. The sampling media were replaced at the end of 24 hours and a second series of 24-hour samples collected. This was repeated to collect a third set of 24-hour samples. Flow rates and sample volumes are summarized in Table 1.

### Environmental Air Sampling

Air samples were collected at three on-site locations indicated in Figure 7, 60-80 m southeast of the SLC stack. Samplers were suspended in trees, approximately 15-20 m above the ground. Each sampler consisted of a particulate filter and a two-stage molecular sieve cartridge. The sampling rate for each unit was 5 l/min. After collection of particulate and aqueous tritium, the air streams from the three samplers were combined. A fraction (1.2 l/min) of this combined stream was passed through an oxidizer furnace and molecular sieve cartridge to determine the average gaseous tritium concentration. A diagram of this system is shown in Figure 8.

Sampling was conducted for 48 hours, with periodic checks to assure proper sampling rates. Wind speed and direction were monitored during the sampling period using a portable weather station, erected on the top of the nearby water tank. The wind rose developed from this data is presented on Figure 9.

### Liquid Effluent Sampling

#### Hold-up Tank

Contents of a hold-up tank were agitated; a sample was withdrawn and split with the licensee for comparison of analytical procedures.

### Other On-Site Samples

#### Surface Soil

Surface soil samples (approximately 1 kg each) were collected at 39 randomly selected locations around the perimeter of the site. Samples were also collected at seven locations where direct radiation measurements identified elevated levels. A sample of sediment was collected from the storm drainage ditch. These sampling points are indicated on Figure 10.

## Subsurface Soil

Boreholes were drilled at 29 on-site locations shown on Figure 11. The deeper holes (1-10) were drilled using a truck-mounted drill rig; the remaining holes (11-29) were drilled with a portable motorized auger unit. Radiation measurements were made at 30 cm intervals in holes 1-10 using a collimated NaI scintillation detector, to identify the presence of subsurface radionuclide deposits. Subsurface soil samples were collected at several depths from these holes and also from holes 11-29.

## Surface Water

Samples of surface water (3.5 l) were obtained from the drainage ditch and the East Lagoon. The locations of these samples are indicated on Figure 12.

## Subsurface Water

Samples of water were collected from the 23 on-site monitoring wells (Figure 3) using either "bailer" or hand pump techniques. Depth of the water level in each of the wells was recorded. Water was also collected from ORAU boreholes 6 and 9 - the other boreholes were not deep enough to reach ground water.

## Vegetation

One kilogram samples of surface vegetation were collected at six on-site locations indicated on Figure 12.

## Off-Site Samples

### Air

A molecular sieve cartridge was placed in a parallel with licensee's off-site sampler located approximately 0.3 km east of the site (Figure 13). This sampler was operated at 1.2 l/min for a period of approximately three days.

### Water

Water samples were collected from four private wells, one private pond, and the city of Bloomsburg water supply. During release of a hold-up tank, samples were also obtained from the Susquehanna River 2 km upstream of the facility, at the outfall, and 100 m, 500 m, and 2 km downstream. Locations of these samples are indicated on Figure 14.

### Soil and Sediment

Figure 15 indicates the location of off-site soil samples collected 0.5 to 1 km from the SLC site. A total of 19 samples were collected including two from an island southeast of the facility. Sediment samples were collected from the Susquehanna River at locations also indicated on Figure 16. Three sediment samples were collected 2 km upstream; one at the SLC liquid effluent outfall; two 100 m downstream; three 500 m downstream; and one 2 km downstream.

### Vegetation

Two samples of surface vegetation were collected from the island southeast of the facility. Vegetables, with high water content, e.g. tomatoes and cucumbers, were collected from four private residences. Locations of these samples are shown on Figure 13.

## Aquatic Life

Samples of aquatic vegetation, macroinvertebrates, and two species of fish were collected from the Susquehanna River in the vicinity of the SLC outfall. Samples of similar aquatic life were collected 0.5 to 1.0 km upstream for comparison purposes.

## Baseline Soil and Water Samples

Six soil and four water samples were collected 2.5 to 10 km from the site. Locations of these samples are indicated on Figure 17. These samples served as baselines for comparison with the other samples collected in the area of the SLC facility.

## Analytical Equipment and Procedures

Samples were returned to laboratories in Oak Ridge for analysis. Air, water, and vegetation samples were analyzed for tritium. Groundwater, surface water, soil, sediment, vegetation, and aquatic organisms were analyzed for Ra-226 and Cs-137. Selected samples were also analyzed for Sr-90. Appendix A contains a list of the major sampling and analytical equipment used for this survey. Analytical procedures are described in further detail in Appendix B.

## RESULTS

### Background Radiation and Baseline Concentrations

Background exposure rates in the Bloomsburg, Pennsylvania, area ranged from 6-10  $\mu$ R/h: slightly higher levels would be expected in the vicinity of buildings or areas of stone fill due to naturally occurring radionuclides in construction materials. Table 2 presents the radionuclide concentrations measured in baseline soil and water samples. Radionuclides, now or previously handled at U.S. Radium and SLC, were not noted in concentrations exceeding the normally occurring ranges.



### Direct Radiation Levels

Gamma radiation levels measured at 1 m above the surface in accessible areas on the U.S. Radium/SLC property are indicated on Figure 18. Exposure rates at the property boundary range from 7 to 33  $\mu\text{R/h}$ . Two generally elevated areas were noted near the boundary - one near the northwest corner (18  $\mu\text{R/h}$ ) and another along the southeast perimeter (33  $\mu\text{R/h}$ ). Elevated levels were also measured in the vicinity of previous U.S. Radium waste disposal areas. The maximum direct radiation measured at 1 m above the surface was 133  $\mu\text{R/h}$ , south and southeast of the East Lagoon.

Higher radiation levels were noted at surface contact at several locations on the property. These locations are shown in Figure 19. The maximum surface exposure rate measured was approximately 1.5 mR/h, at several locations near areas of previous waste disposal. Comparisons of open- and closed-shield G-M detector measurements indicated that these radiation levels are primarily due to gamma emitting radionuclides, with only a small nonpenetrating radiation component. The direct radiation levels measured at the surface and 1 m above the surface are below the NRC guidelines that limit the dose in unrestricted areas to a maximum of 2 mrem in any hour with less than 100 mrem accumulation possible during any seven consecutive days.<sup>1</sup> The pattern of the direct radiation indicates small regions of surface contamination that suggests both isolated surface residues and migration from waste disposal areas.

### Air Monitoring Results

#### Stack Effluent Concentrations

Results of the stack effluent monitoring are presented in Table 3. The levels of aqueous and gaseous tritium measured in the stack on all three days of monitoring were much less than anticipated. Later, examination revealed a poor connection in the sampling system,

which permitted a substantial leakage of outside air into the section containing the molecular sieve collectors. During the same sampling periods, the stack concentrations determined by SLC were in agreement with ORAU results for the particulate tritium. However, the aqueous and gaseous tritium concentrations reported by SLC were all much greater than those determined by ORAU; results differed by factors ranging from 10 to as high as almost 1000. These differences are believed due to the leakage in the collection system and the ORAU results are considered incorrect.

It should be noted that based on licensee-reported data, the three-day average concentration of aqueous tritium, in the facility exhaust air at point of discharge (18 m above ground level), was approximately 0.9 and 23 times the average annual limits for restricted and unrestricted areas respectively. The licensee advised the authors later that the 1981 data for soluble tritium are high by approximately 33%, due to a revision in calibration factors. Hence, the ratios listed above would be reduced to 0.7 and 17, respectively.

#### On-Site Environmental Samples

The three on-site air samples collected southeast of the stack in the prevailing downwind direction, contained concentrations of all forms of tritium well below the guideline levels for unrestricted areas. These levels are presented in Table 3. Use of this data to confirm the licensee's dilution factors for stack discharges would not be reliable, because of the very small fraction (2-3%) of the sampling period that the wind was in the direction of the samplers.

#### Off-Site Air Sample

The concentration of aqueous tritium, measured in the sample collected off-site was  $<5.1 \times 10^{-12}$   $\mu\text{Ci/ml}$ . This level was much less than the guideline level of  $2 \times 10^{-7}$   $\mu\text{Ci/ml}$ . It is also much less than the concentration measured by the licensee at this location; however, the licensee sampler ran for seven days, compared to three days for the ORAU sampler, and during this three-day period the wind was not in the direction of the sampler (refer to the wind rose in Figure 9).

## On-Site Water Samples

### Hold-up Tank

The concentration of tritium measured in the hold-up tank sample was  $4.1 \times 10^{-2}$   $\mu\text{Ci/ml}$ , which corresponds well with the SLC result of  $3.7 \times 10^{-2}$   $\mu\text{Ci/ml}$  (Table 4). Dilution and release of this tank to meet the average annual limit for unrestricted areas of  $3 \times 10^{-3}$   $\mu\text{Ci/ml}$  were conducted over a period of approximately 24 hours.<sup>1</sup>

### Surface Water

Table 4 presents the radionuclide concentrations in on-site surface water from the drainage ditch and the East Lagoon. The Ra-226 concentrations in these two samples ( $3.3 \times 10^{-10}$  and  $3.0 \times 10^{-10}$   $\mu\text{Ci/ml}$ ) were approximately twice that of the baseline water. The Sr-90 concentration in the drainage ditch water was  $6.4 \times 10^{-9}$   $\mu\text{Ci/ml}$ . The concentration of tritium in the East Lagoon was  $7.14 \times 10^{-6}$   $\mu\text{Ci/ml}$  - about three times the level of the maximum baseline sample; the tritium concentration in water from the drainage ditch was  $6.1 \times 10^{-7}$   $\mu\text{Ci/ml}$ , which is in the range of the baseline samples. Concentrations of all radionuclides in these samples were below the average annual guideline level for unrestricted areas.

### Subsurface Water

The radionuclide concentrations in subsurface water samples from the 23 monitoring wells and 2 boreholes are presented in Table 5. The maximum tritium level of  $7.22 \times 10^{-5}$   $\mu\text{Ci/ml}$  was measured in water from well 21; wells 4, 9, 20, and 22 also contained tritium concentrations above  $1 \times 10^{-5}$   $\mu\text{Ci/ml}$ . While almost all subsurface water samples contained tritium concentrations above the baseline levels for surface water, all were below the NRC guideline of  $3 \times 10^{-3}$   $\mu\text{Ci/ml}$  for unrestricted areas.<sup>1</sup>

Ra-226 concentrations were in the range of baseline water, with the exception of the sample from well 5, which had a concentration of  $9.1 \times 10^{-9}$   $\mu\text{Ci/ml}$ . The maximum Cs-137 concentration of  $5.7 \times 10^{-8}$   $\mu\text{Ci/ml}$  was noted in well 13. These Ra-226 and Cs-137 concentrations are below the NRC guideline levels, for unrestricted areas or  $3 \times 10^{-8}$   $\mu\text{Ci/ml}$  and  $2 \times 10^{-5}$   $\mu\text{Ci/ml}$  respectively.<sup>1</sup>

Monitoring wells 1, 3 and 4 contained Sr-90 concentrations of  $6.21 \times 10^{-5}$ ,  $2.13 \times 10^{-6}$ , and  $4.77 \times 10^{-7}$   $\mu\text{Ci/ml}$  respectively. These concentrations exceed the NRC guideline levels of  $3 \times 10^{-7}$   $\mu\text{Ci/ml}$  for unrestricted areas. Higher concentrations in these wells are believed due to migration from the previous disposal area north of their locations.

The EPA drinking water levels have also been provided on Table 5 for comparison.<sup>2</sup>

#### On-Site Soil

Radionuclide concentrations in on-site surface and subsurface soil samples are presented in Tables 6 and 7 respectively. Surface samples from locations 4, 29, and 40B at the northwest corner of the facility contained elevated Ra-226 concentrations of 2.3, 5.8, and 57 pCi/g respectively. A subsurface sample from a depth of 0.3 m at location 29 also had an elevated Ra-226 concentration of 4.1 pCi/g. All other soil samples containing Ra-226, Cs-137, or Sr-90 concentrations exceeding 1.5 pCi/g (approximately twice the maximum baseline concentrations) were from the southern portion of the property. Concentrations in "biased" surface samples collected from areas of maximum direct radiation levels, contained up to 672 pCi/g of Ra-226, 631 pCi/g of Cs-137, and 15.4 pCi/g of Sr-90. Several subsurface samples from this flood plain area also contained elevated radionuclide concentrations. The maximum subsurface level was 286 pCi/g of Cs-137 in a sample collected from 0.3 m deep at location 10. Figure 20 indicates the locations of these on-site soil

samples containing greater than 1.5 pCi/g of Ra-226, Cs-137, or Sr-90. These locations correlate well with the direct radiation levels on the property (refer to Figures 18 and 19 and the above discussion of radiation measurements).

#### On-Site Vegetation

Radionuclide concentrations in on-site vegetation samples are presented in Table 8. Sample V6 from south of the SLC facility had the highest concentration of tritium at 424 pCi/g; sample V5 contained 2.8 pCi/g of Cs-137. None of the samples had significant Ra-226 concentrations.

#### Off-Site Samples

Results of analysis of off-site samples of vegetation, soil, water, river sediment, vegetation, and aquatic organisms are presented in Tables 8, 9, 10, 11, and 12 respectively. No radionuclides now or previously used in the U.S. Radium and SLC operations were detected in concentrations which are significant in comparison with baseline concentrations or guideline levels. This indicates that there has been no off-site accumulation of radioactive materials as a result of operations at this facility.

### SUMMARY

An environmental radiological survey was performed June 8-12 and August 24-28, 1981, at the Safety Light Corporation (and U.S. Radium) in Bloomsburg, Pennsylvania. Direct radiation levels measured on the site were elevated at some locations but were below federal guidelines for unrestricted areas.

Monitoring to evaluate the licensee's stack effluent control program was inconclusive due to a defect (discovered after the survey) in the sampling system. Environmental air sampling indicated concentrations below the unrestricted area guidelines; however, these results must also be considered indefinite, because of the abnormal wind pattern during the sampling period. Analysis performed by both ORAU and SLC on a liquid sample from a hold-up tank yielded comparable results.

The results of direct measurements and on-site sampling indicate elevated concentrations of Ra-226, Cs-137, and Sr-90 in surface and subsurface soils. With the exception of the area near the northwest corner of the U.S. Radium property, the locations of the contaminated soils are in the vicinity of previous disposals of operational waste. While these contamination levels do not pose a potential hazard to employees or the general public, they do suggest possible radionuclide migration or physical transport from these disposal sites. Levels of tritium and Sr-90 in several of the monitoring wells exceeded NRC or EPA guidelines. These findings also are evidence of migration of radionuclides from the site.

Samples of various environmental media from the vicinity of the properties did not contain levels of radionuclides that would indicate accumulation resulting from SLC or previous U.S. Radium operations.

Equipment malfunctions prevented evaluation of the SLC stack effluent monitoring procedures. Tritium concentrations in other on- and off-site samples, however, indicate the environmental monitoring and control program for current operations at SLC is adequate, and that reliable data are being generated by the licensee for confirming

compliance with the federal regulations. There is evidence that radioactive wastes, remaining from previous U.S. Radium operations, are migrating into the soil and ground water. While these radionuclides do not presently appear to be accumulating off-site, they may be the source of future environmental concerns and the need to remove or stabilize these materials should receive further consideration.

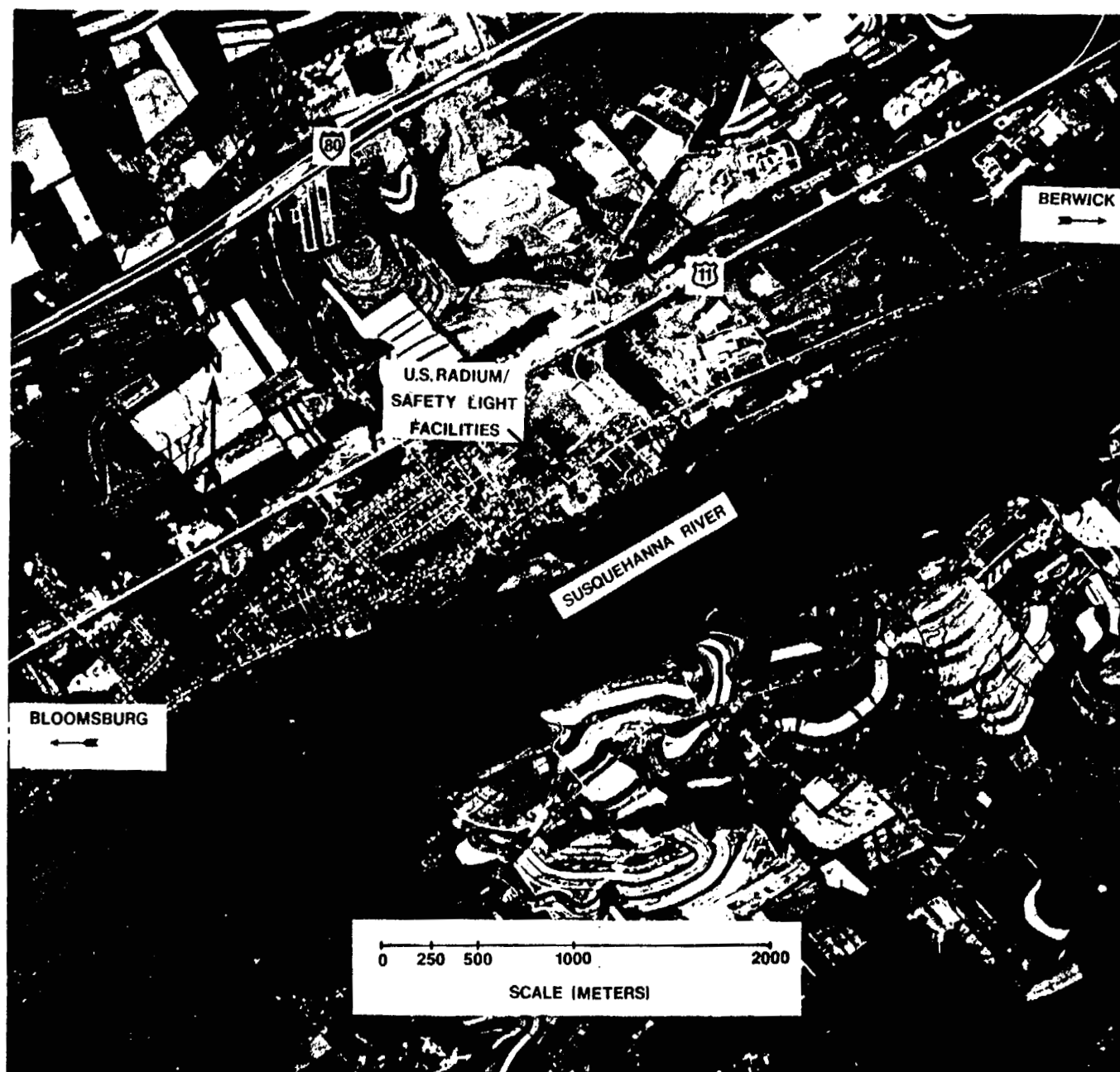


FIGURE 1. Photo of a Portion of Columbia County, Pennsylvania, Showing the Location of the U.S. Radium/Safety Light Corporation.



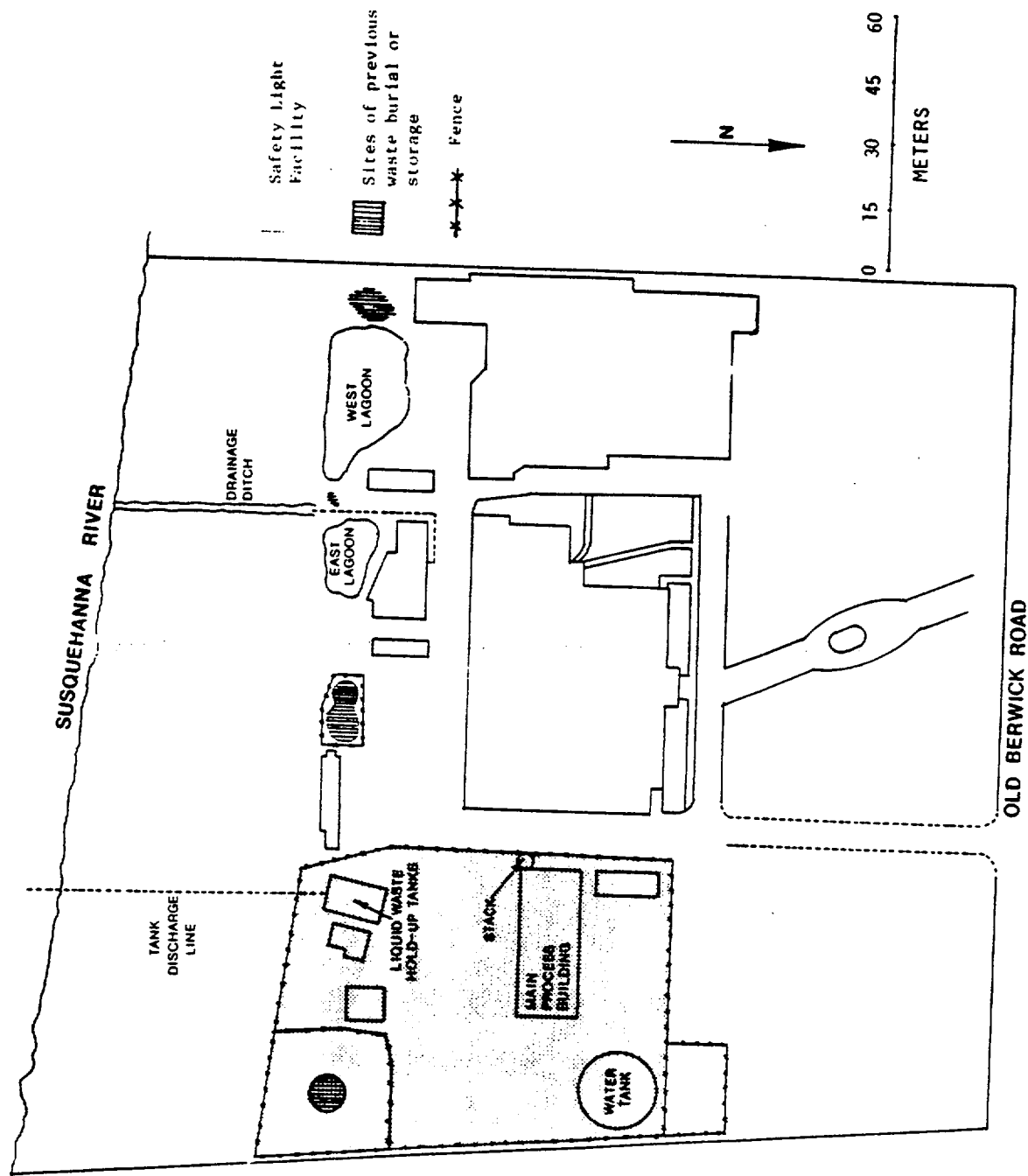


FIGURE 2. Plot Plan of the U.S. Radium Site Indicating the Area Occupied by Safety Light Corporation.

*Handwritten note:* → buried in water

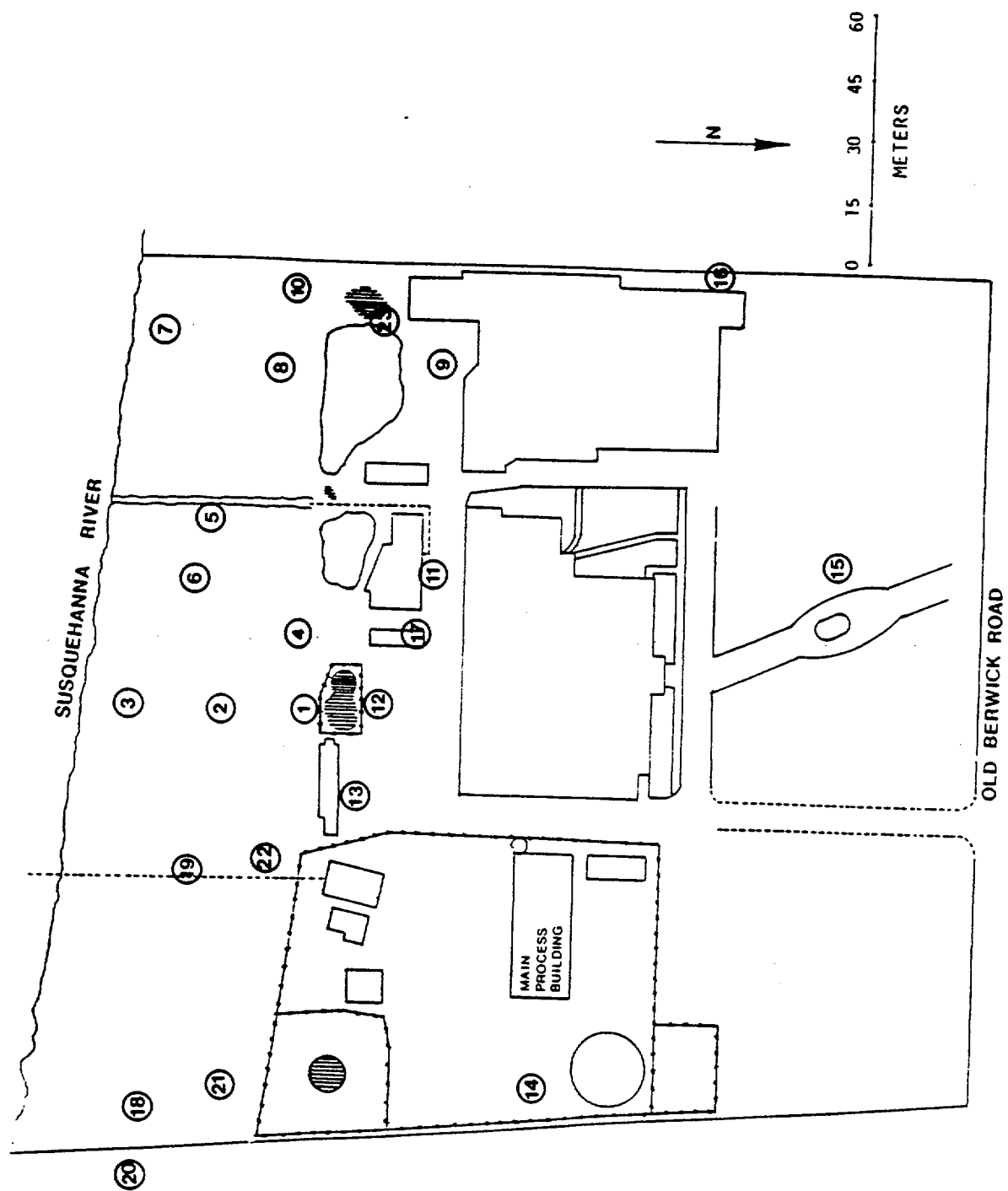
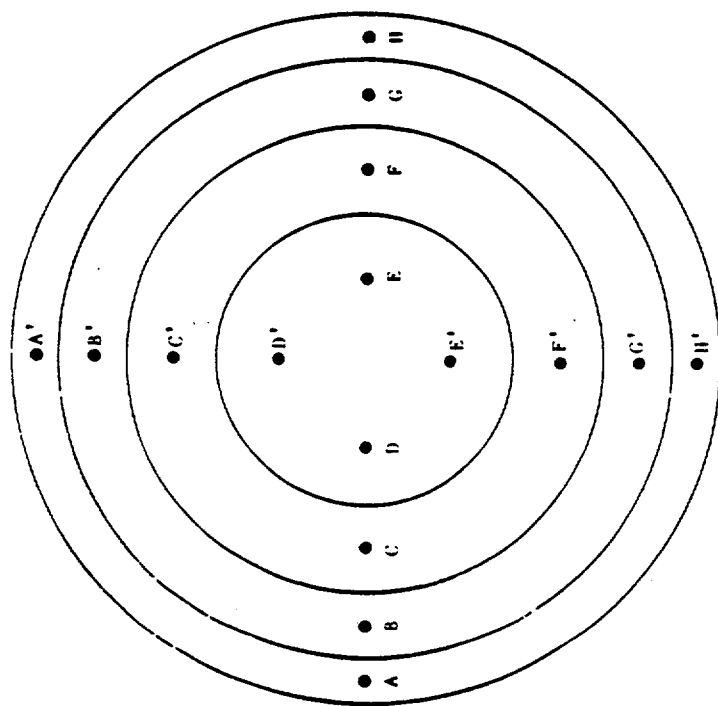


FIGURE 3. Locations of Permanent Ground Water Monitoring Wells Installed by the Licensee.





Duct Diameter (cm)	# of Points Per Traverse	DISTANCES OF POINTS FROM DUCT WALL (fraction of duct diameter)											
		A	B	C	D	E	F	G	H	I	J	K	L
< 61	8	.032	.105	.194	.323	.677	.806	.895	.968	-	-	-	-
> 61	12	.021	.067	.118	.177	.250	.356	.644	.750	.823	.882	.933	.979

FIGURE 4. EPA Standard Method 1 Criteria for Performing Air Velocity Measurements in Circular Ducts.

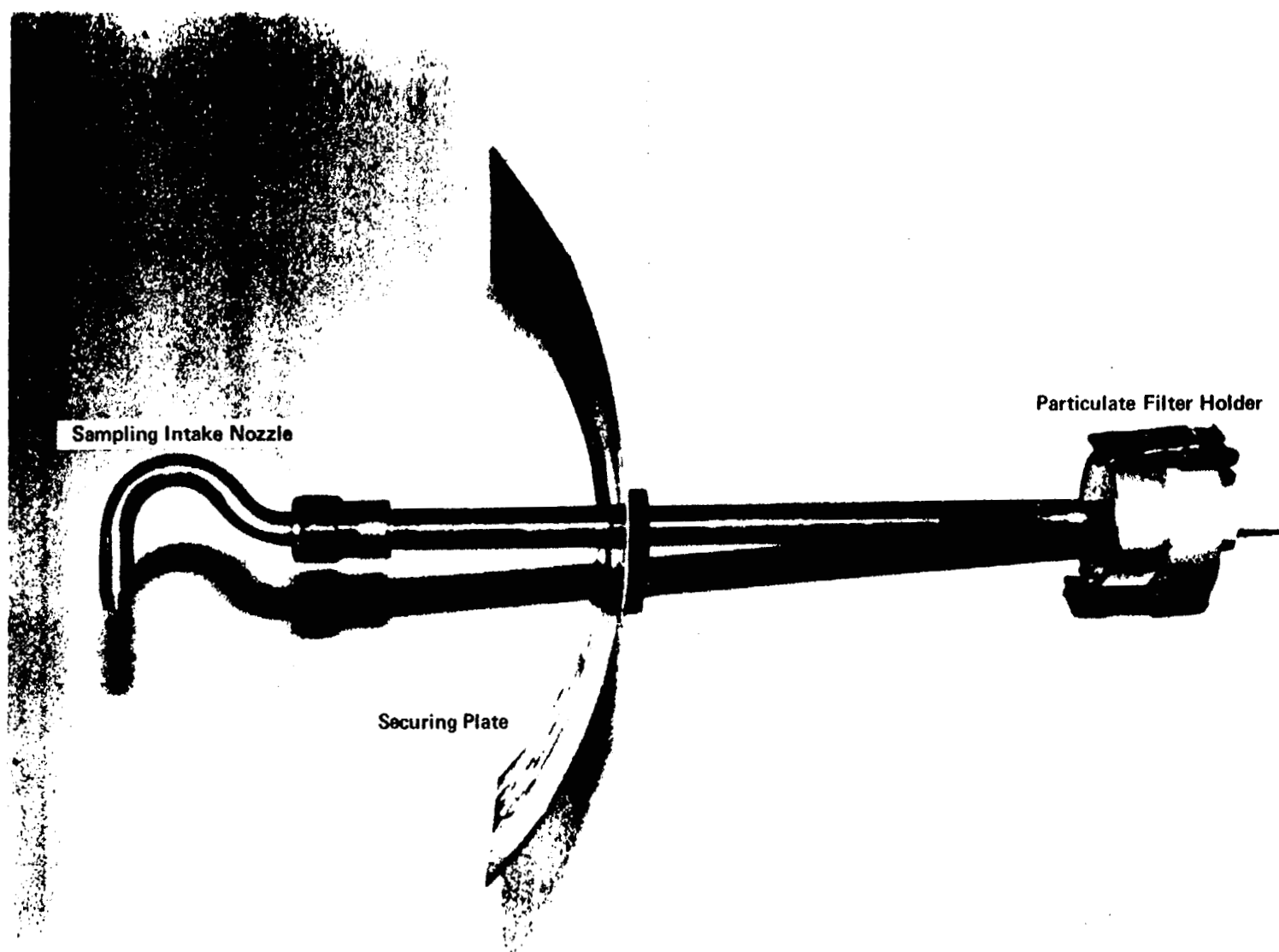


FIGURE 5. Photograph of a Stack Sampling Probe Showing the Sampling Nozzle, Positioning Plate, and In-Line Particulate Filter Holder. (For this photograph the nozzle has been rotated 90° from its usual position relative to the positioning plate.)

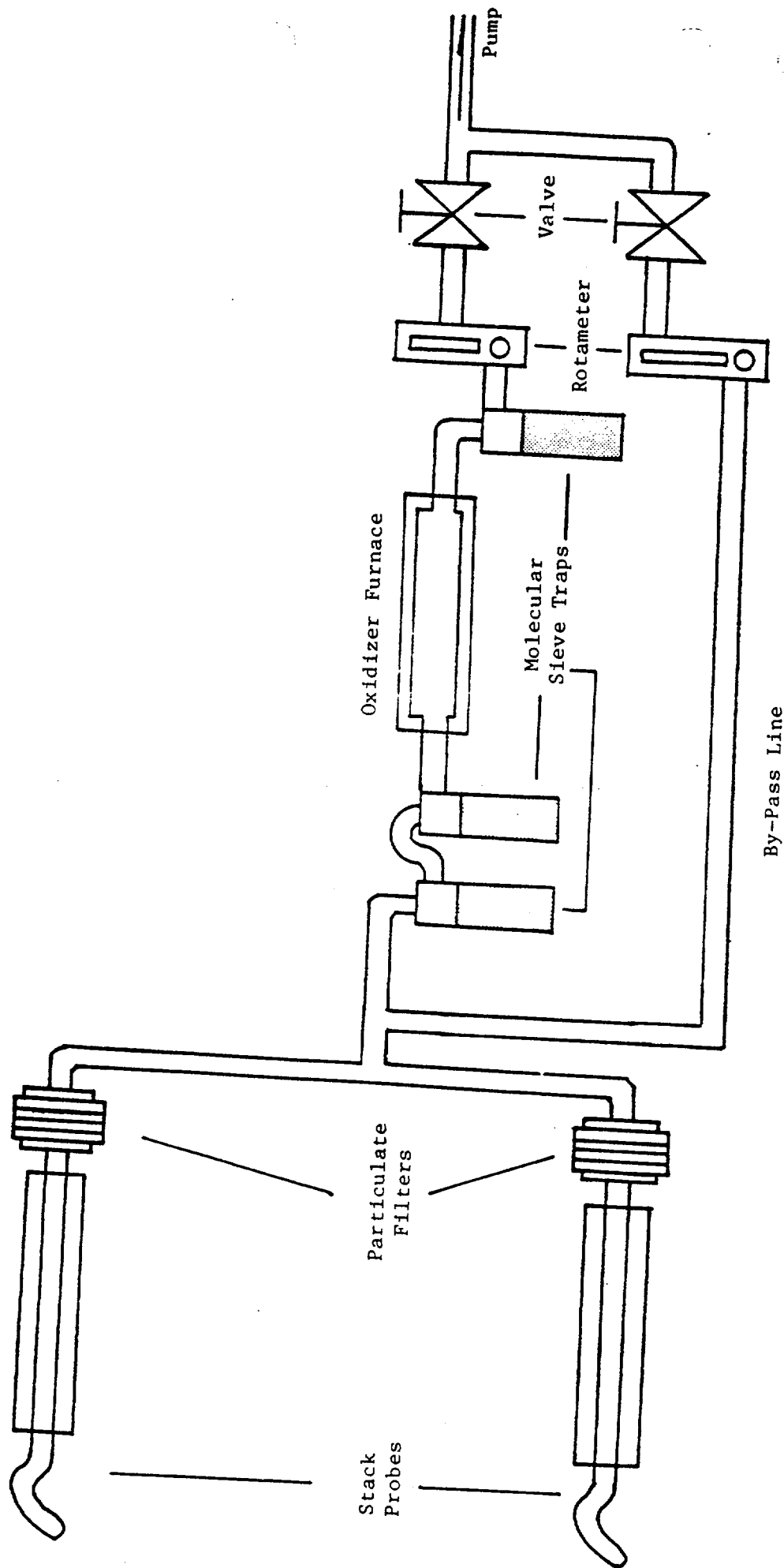


FIGURE 6. Diagram of Stack Sampling System for Particulate, Aqueous, and Gaseous Tritium.

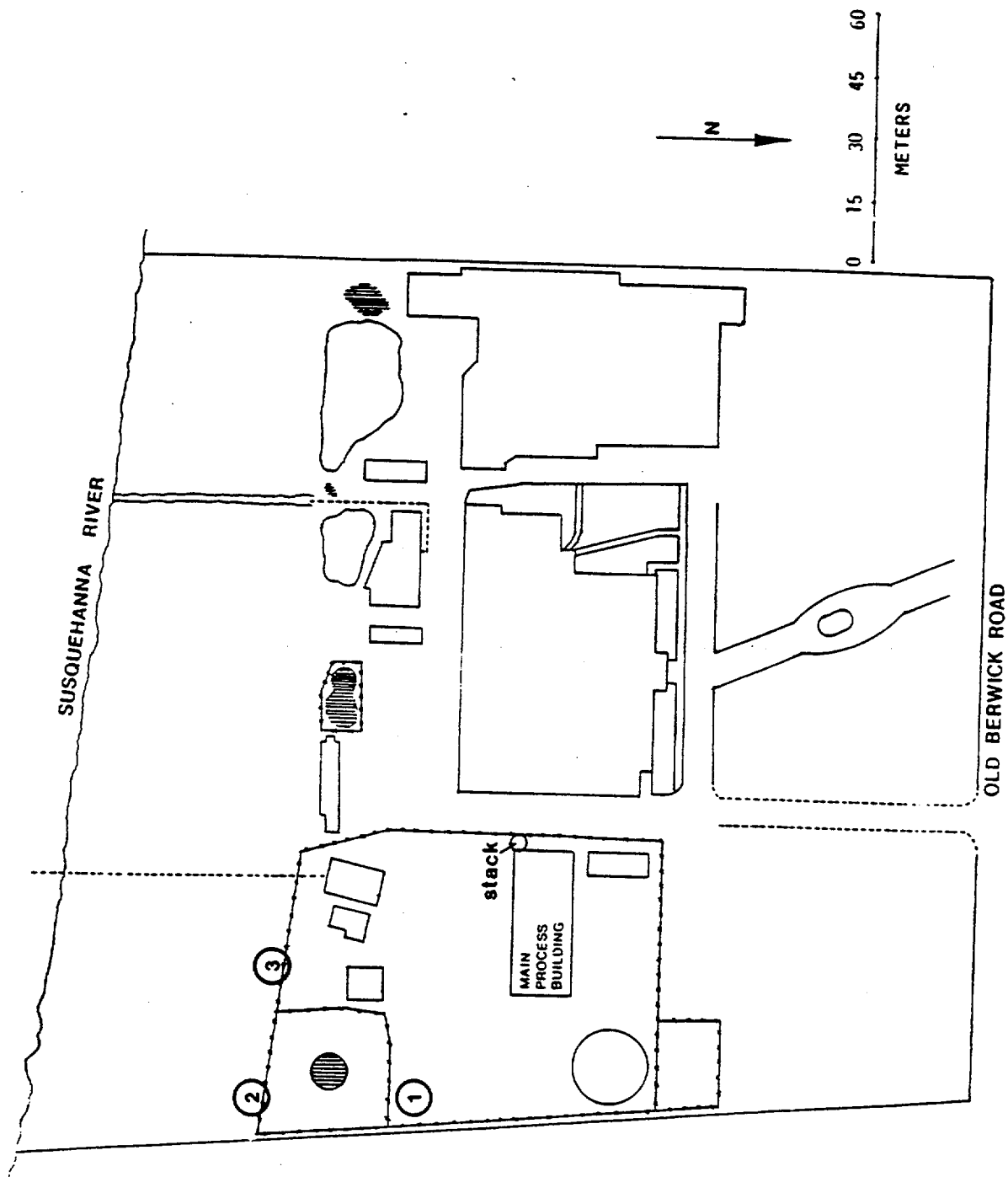


FIGURE 7. Location of On-Site Environmental Air Sampling Stations.

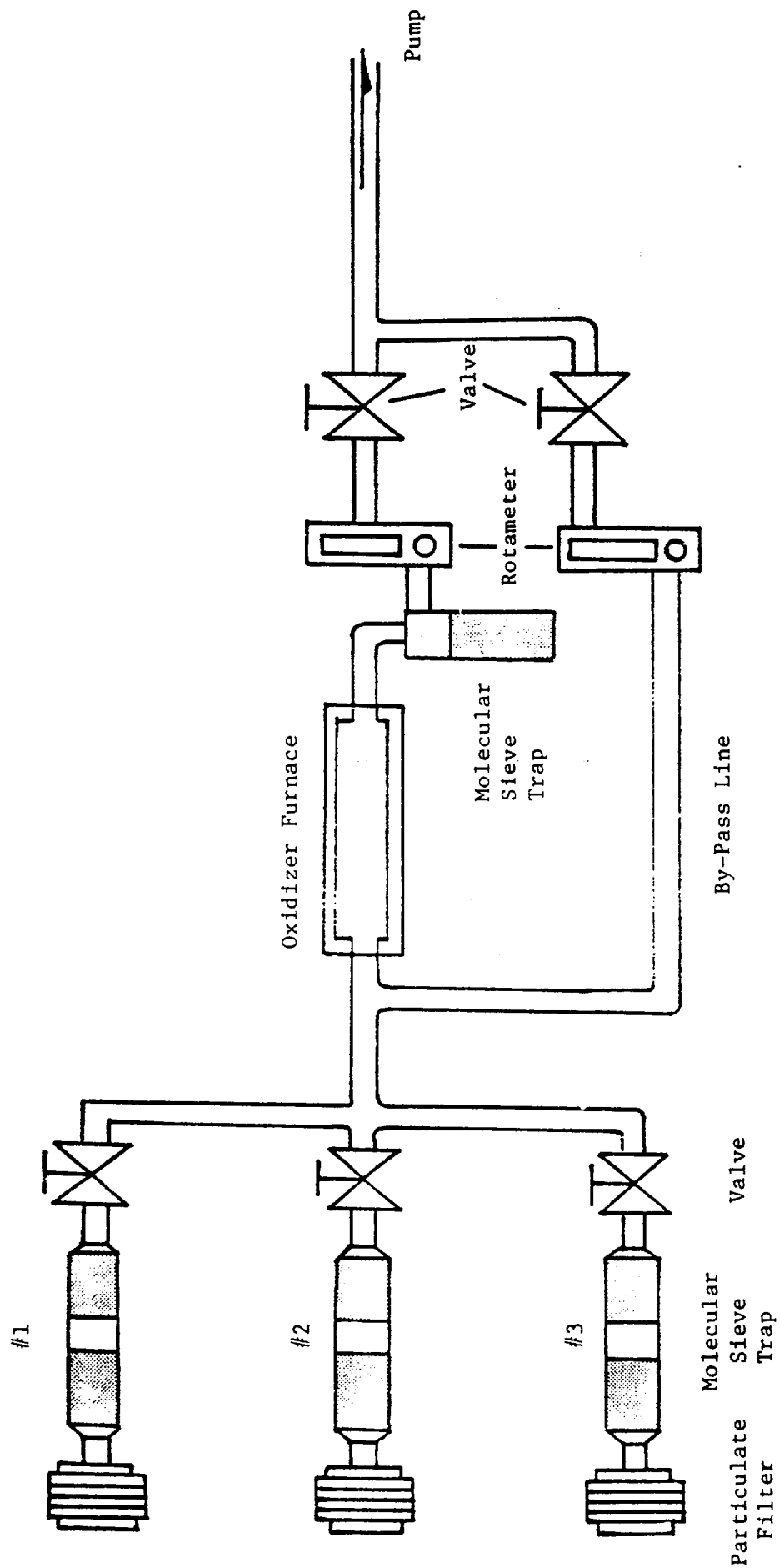


FIGURE 8. Diagram of Environmental Air Sampling System for Tritium.



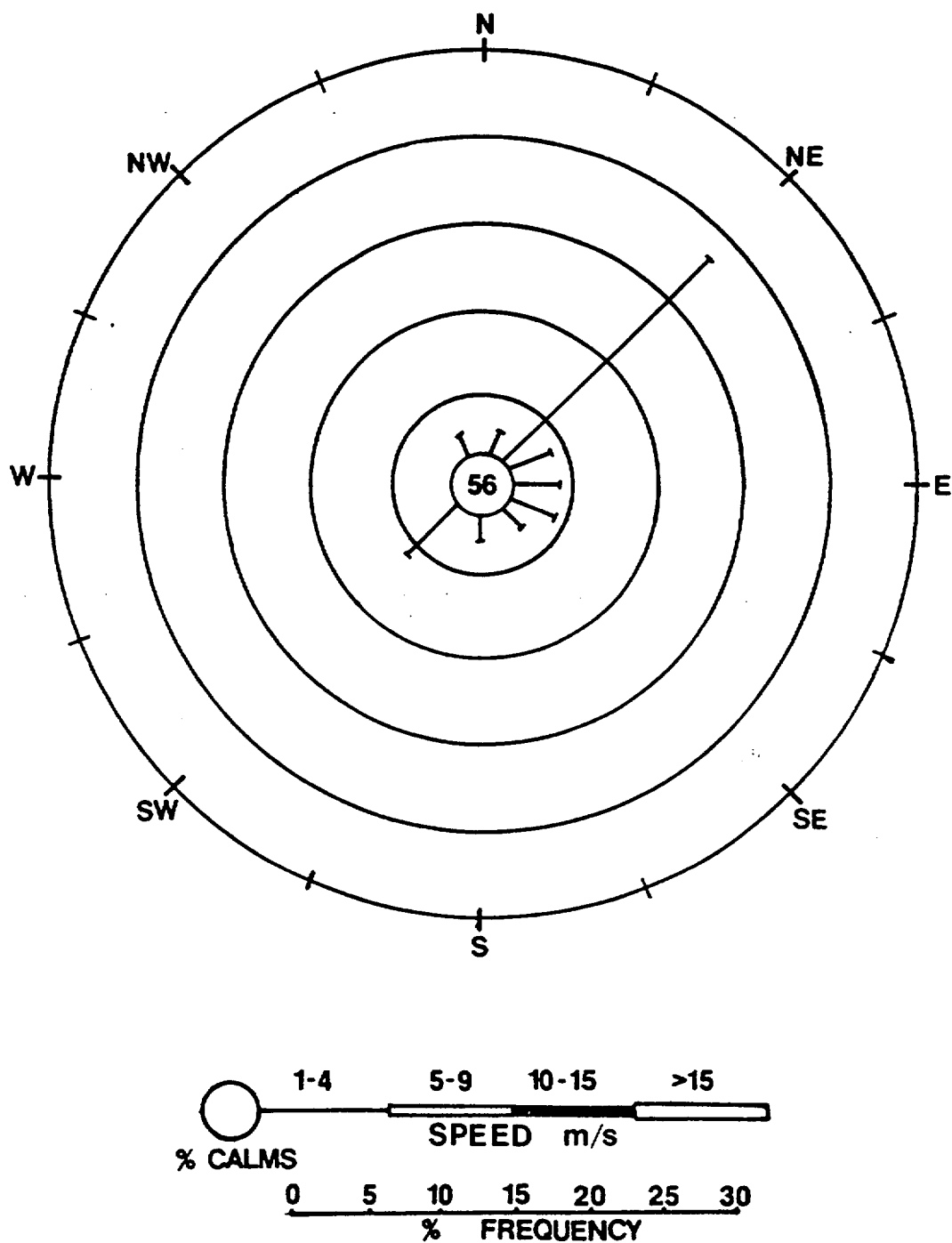


FIGURE 9. Wind Rose for Bloomsburg, Pennsylvania, Area During the Survey Period of August 25-28, 1981.

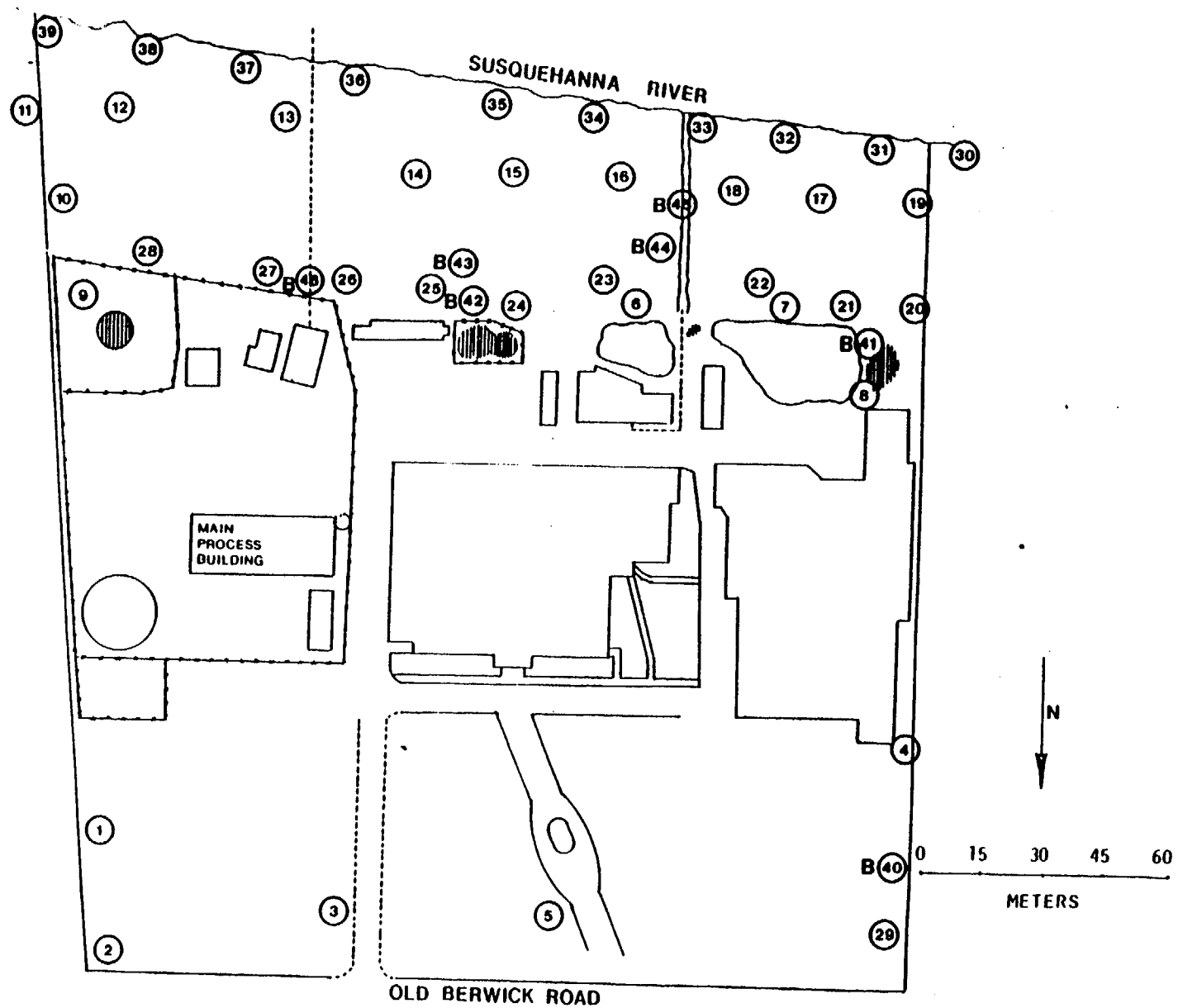


FIGURE 10. Location of On-Site Surface Soil Samples.  
 ("Biased" samples from locations of elevated surface radiation levels  
 are identified by a "B".)

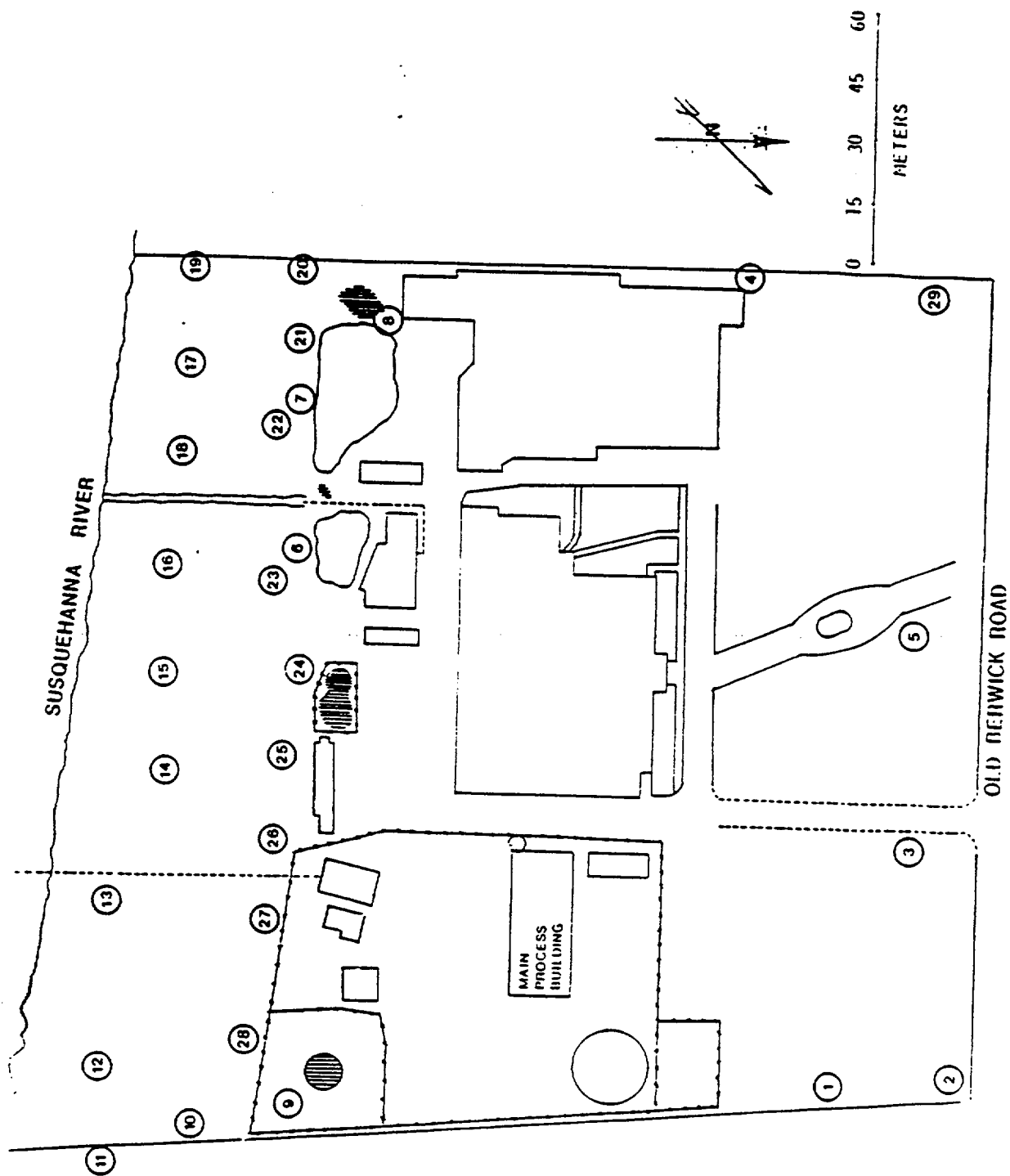


FIGURE 11. Location of On-Site Subsurface Soil Samples.

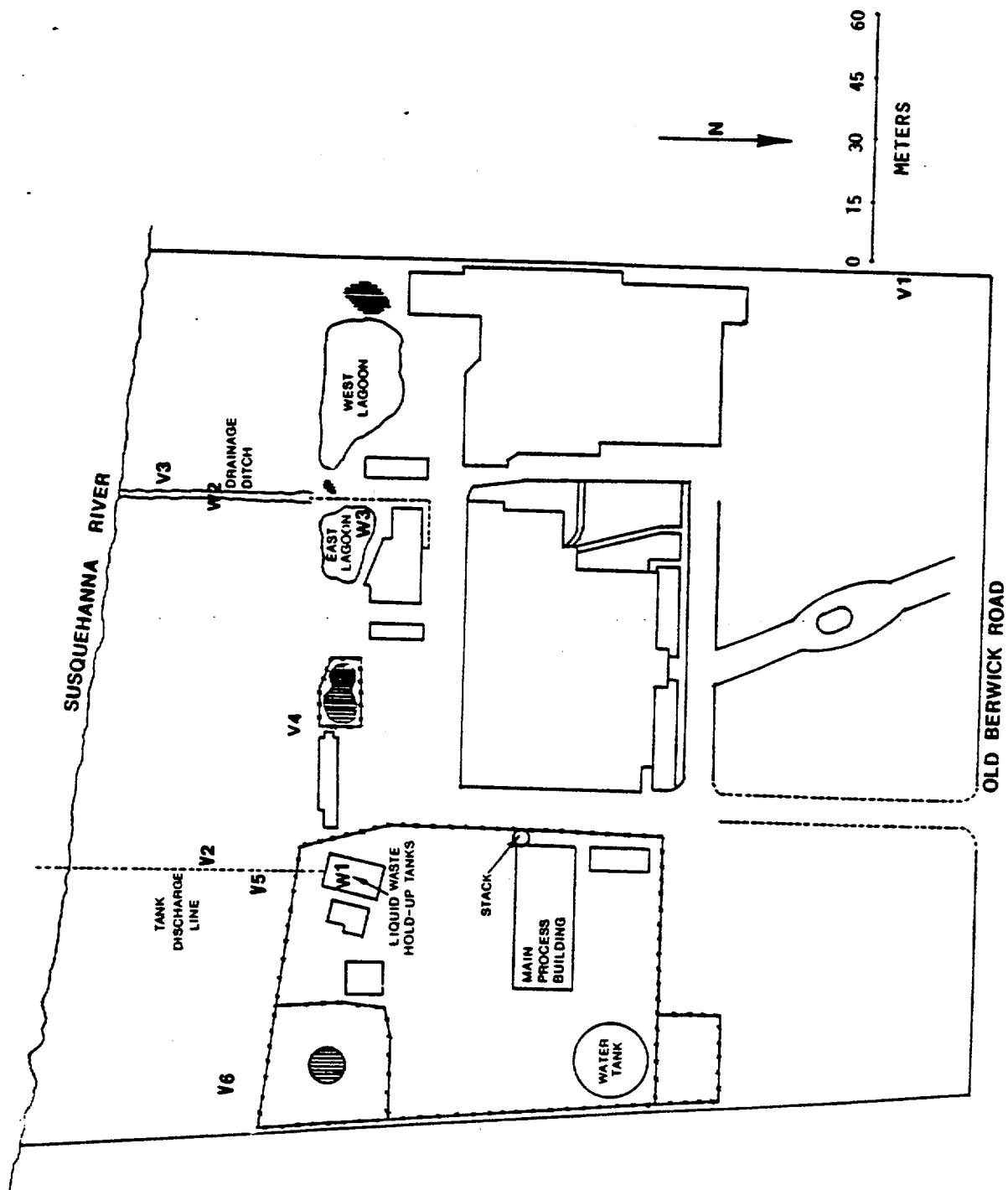


FIGURE 12. Locations of On-Site Surface Water and Vegetation Samples.



FIGURE 13. Locations of Off-Site Environmental Air and Vegetation Samples.

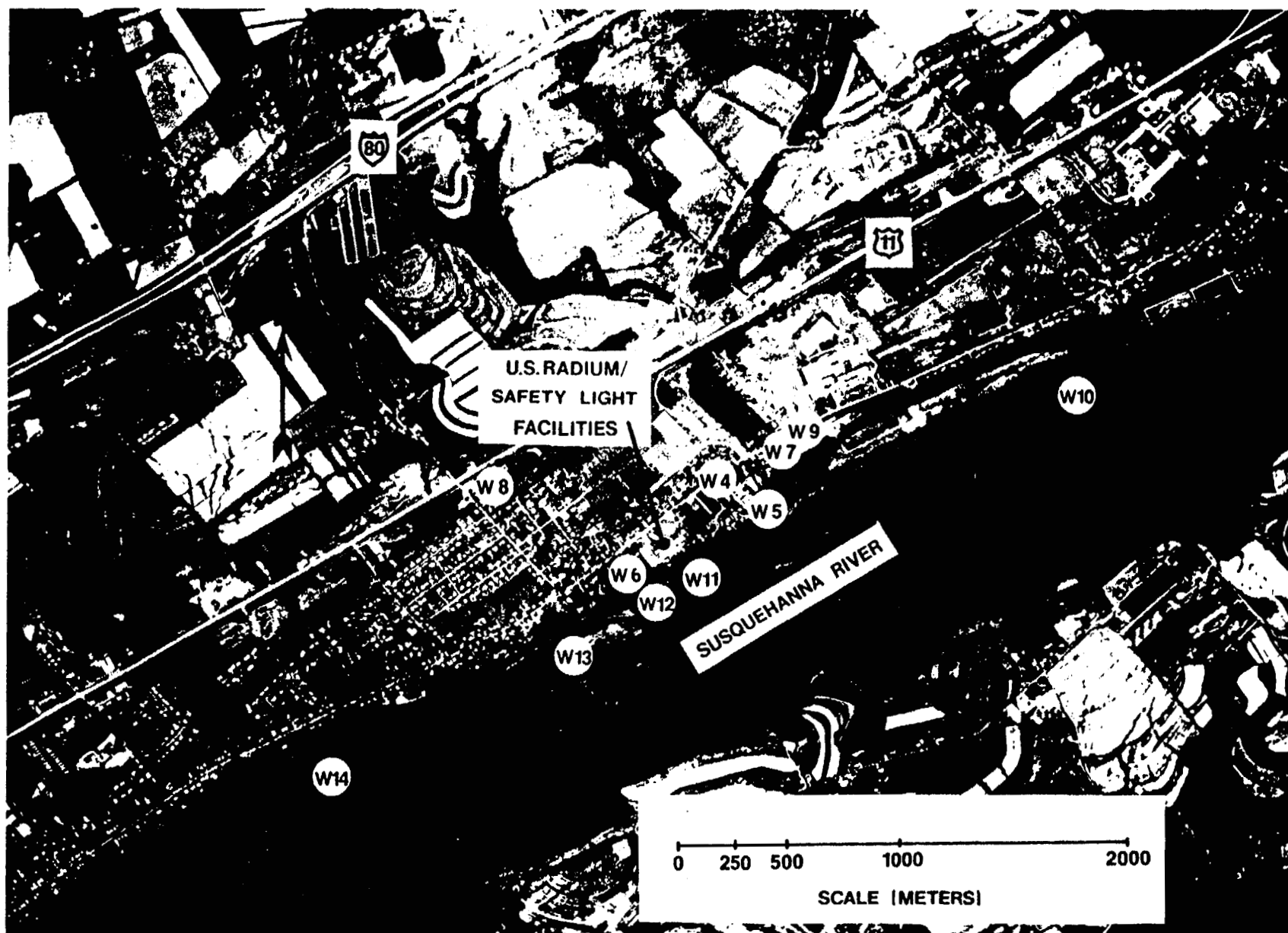


FIGURE 14. Locations of Off-Site Water Samples.



FIGURE 15. Locations of Off-Site Soil Samples.

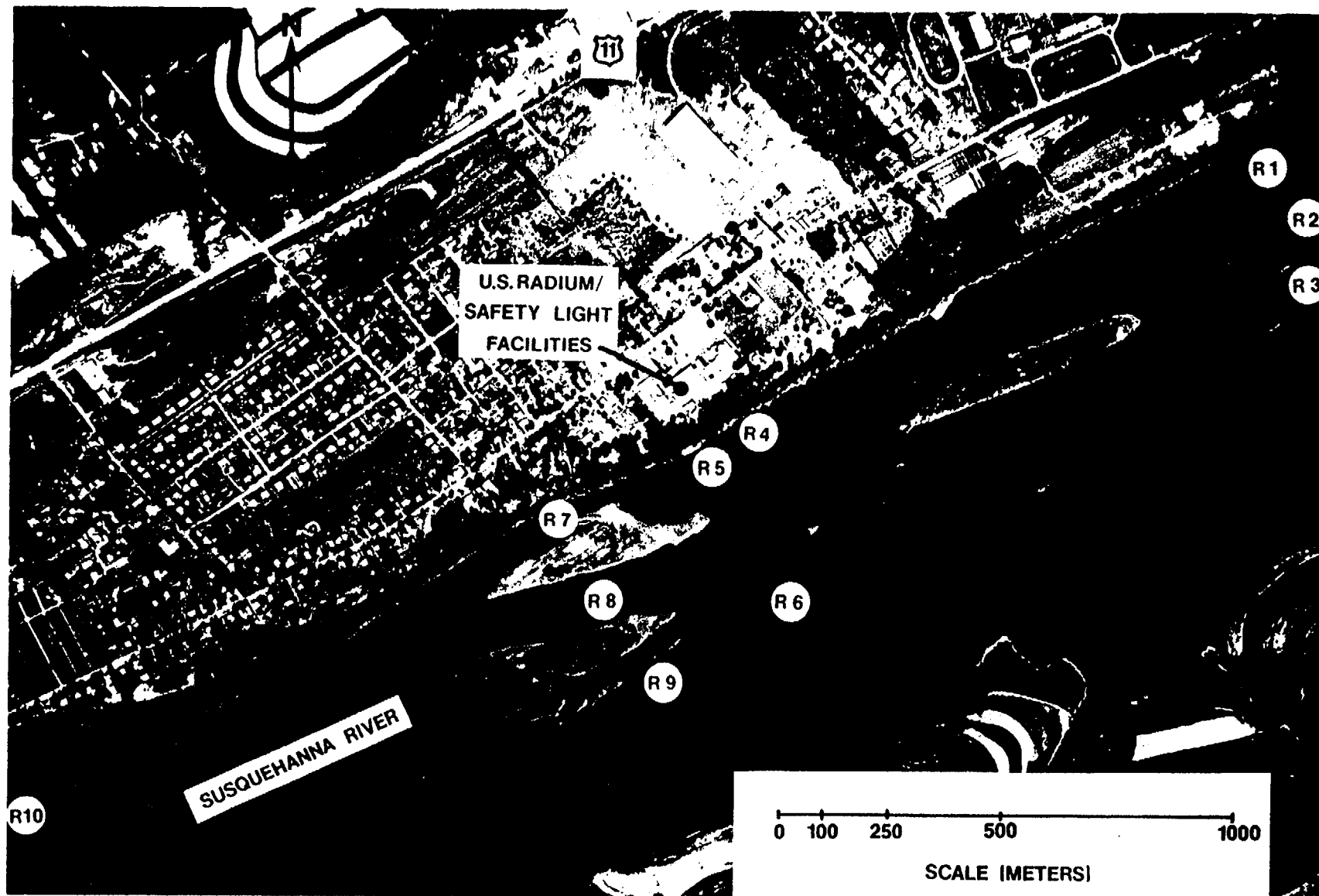


FIGURE 16. Locations of Off-Site River Sediment Samples.



# **U.S. RADIUM/ SAFETY LIGHT FACILITIES**

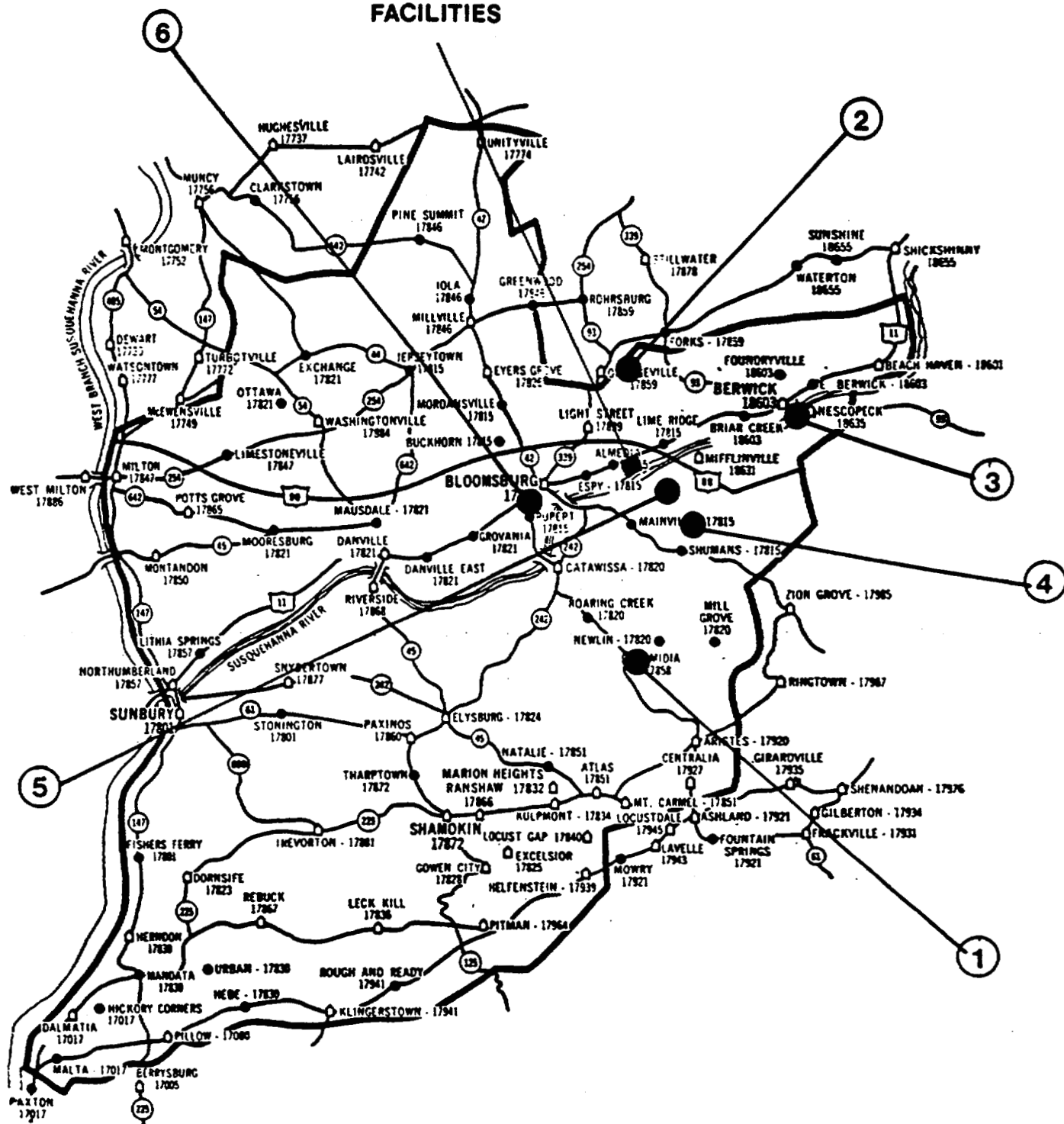


FIGURE 17. Locations of Baseline Soil and Water Samples from the Bloomsburg, Pennsylvania, Area.

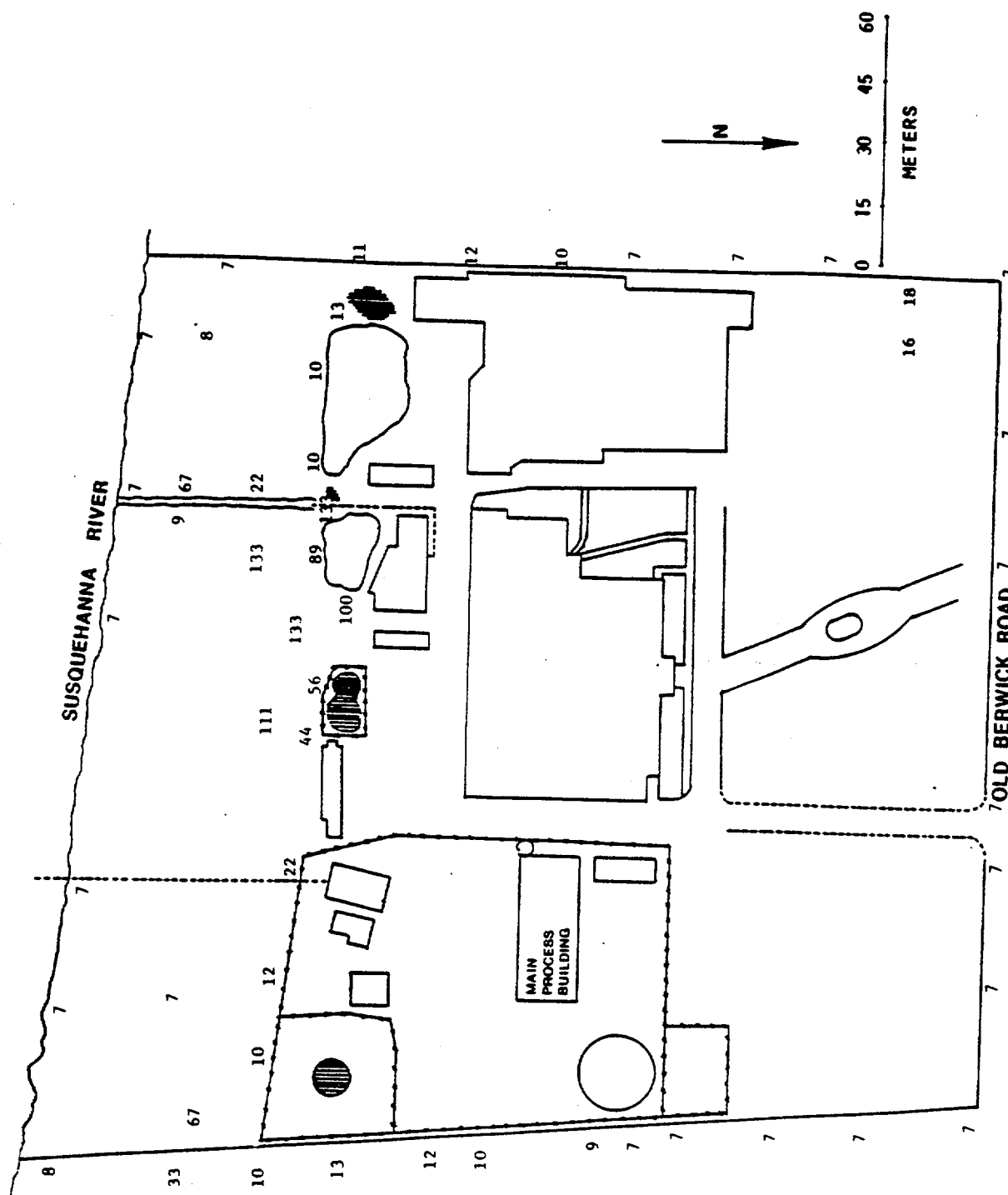


FIGURE 18. Plot Plan of the U.S. Radium/SiC Site Indicating Radiation Exposure Rates ( $\mu\text{R/h}$ ) at 1 meter above the Ground Surface.

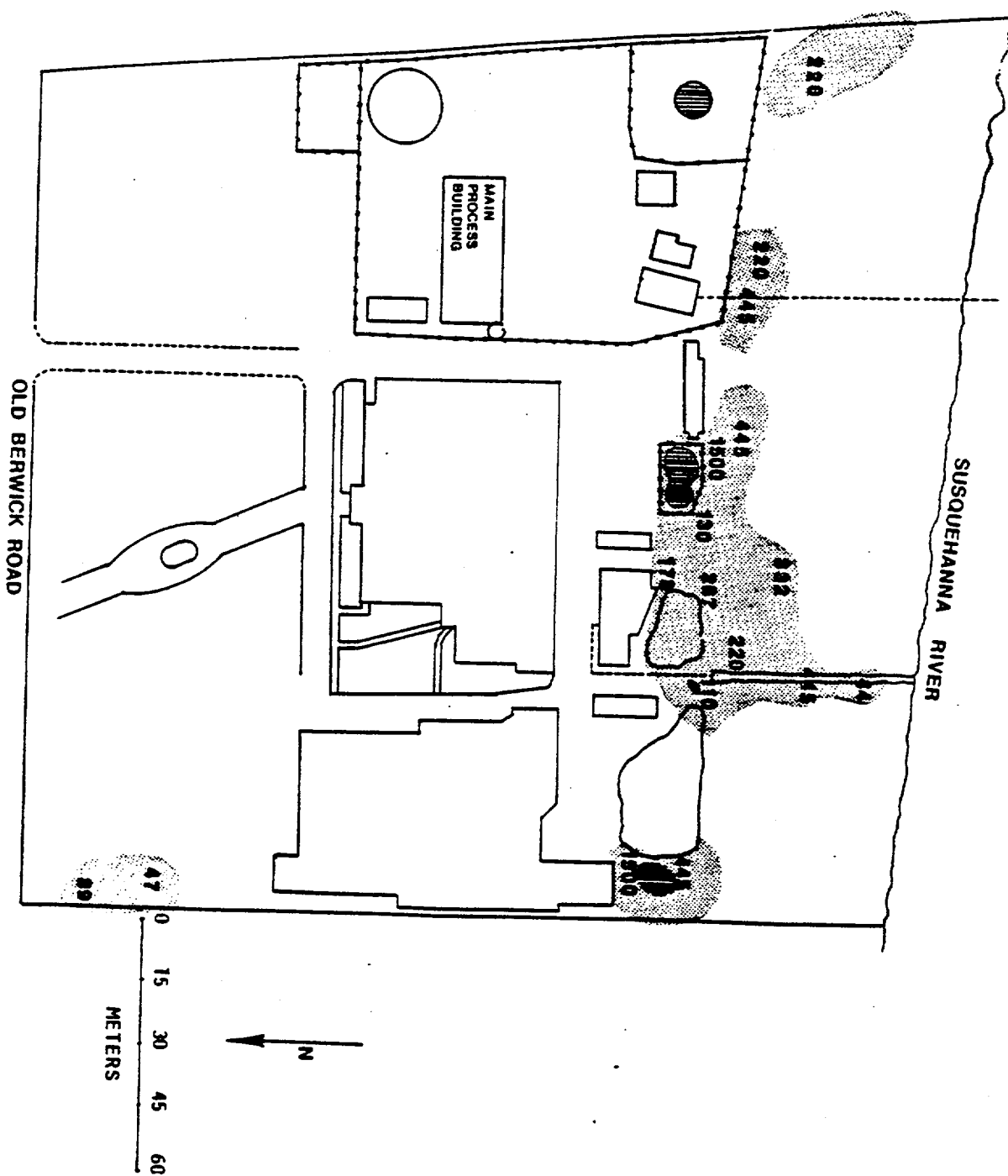


FIGURE 19. Locations of Elevated Surface Radiation Levels on the U.S. Radium/SLC Site. Maximum exposure rates ( $\mu\text{R}/\text{h}$ ) also are indicated.

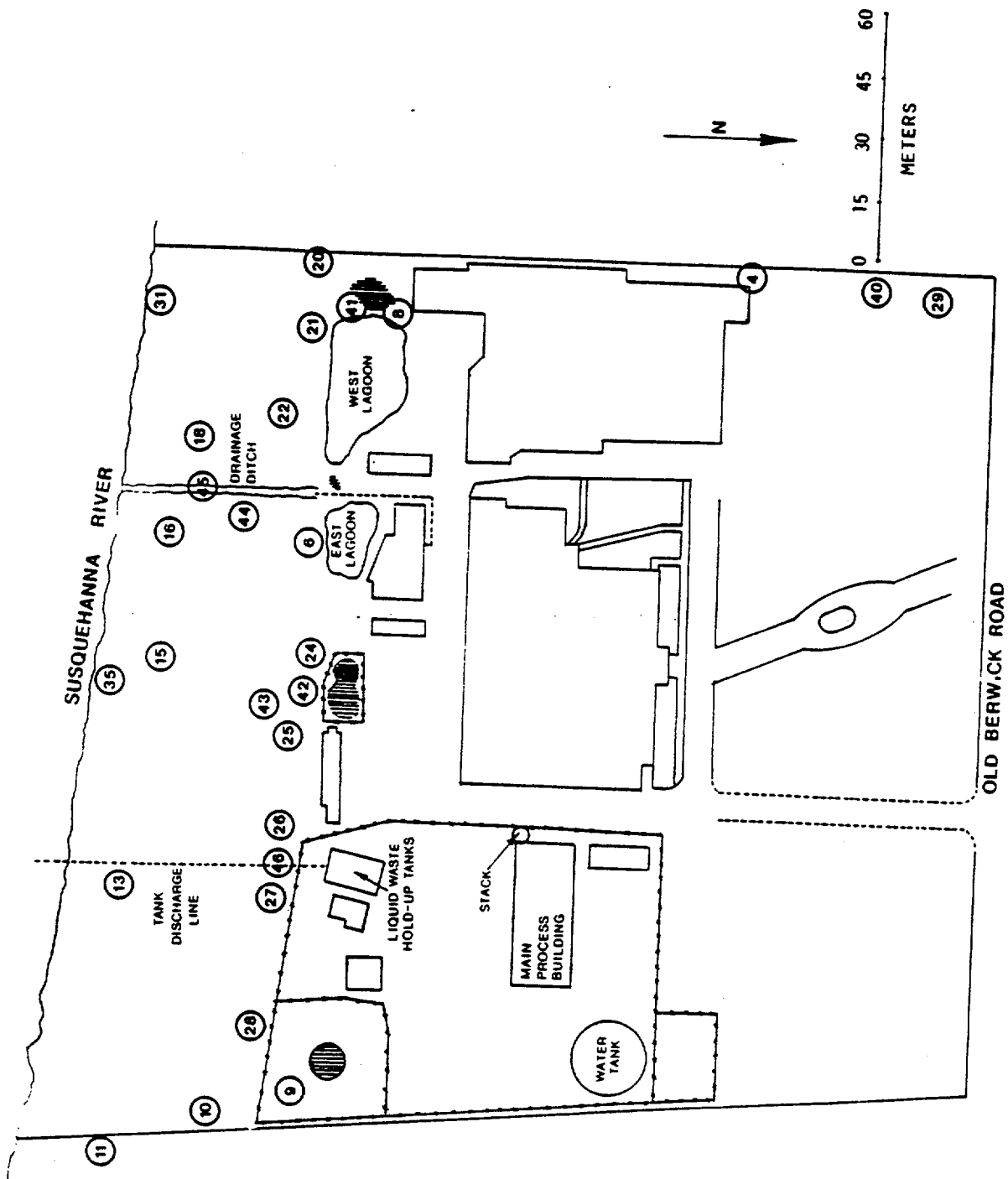


FIGURE 20. Locations of On-Site Soil Samples Containing Concentrations of Ra-226, Cs-137, or Sr-90 Exceeding Twice the Baseline Levels.

TABLE 1

## AIR SAMPLING FLOW RATES AND VOLUMES

Sample Type	Sampling Location	Velocity at Sampling Point (m/min)	Initial Sampling Rate (l/min)	Date	Sampling Time (min)	Sample Volume <sup>a</sup> (l)	Sampling Media
Stack	A	636	10.2	8/25-26/81	1430	$1.42 \times 10^4$	particulate filter
	B	560	10.2	8/25-26/81	1430	$1.42 \times 10^4$	particulate filter
	Combined A & B Streams	NA (not applicable)	1.0	8/25-26/81	1430	$1.36 \times 10^3$	molecular sieve, oxidizer furnace, molecular sieve
	A	636	10.2	8/26-27/81	1440	$1.39 \times 10^4$	particulate filter
	B	560	10.2	8/26-27/81	1440	$1.39 \times 10^4$	particulate filter
	Combined A & B Streams	NA	1.0	8/26-27/81	1440	$1.36 \times 10^3$	molecular sieve, oxidizer furnace, molecular sieve
	A	636	10.2	8/27-28/81	1440	$1.17 \times 10^4$	particulate filter
	B	560	10.2	8/27-28/81	1440	$1.17 \times 10^4$	particulate filter
	Combined A & B Streams	NA	1.0	8/27-28/81	1440	$1.01 \times 10^3$	molecular sieve, oxidizer furnace, molecular sieve
Environmental On-Site <sup>b</sup>	1	NA	5.0	8/26-28/81	2880	$1.44 \times 10^4$	particulate filter and molecular sieve
	2	NA	5.0	8/26-28/81	2880	$1.44 \times 10^4$	particulate filter and molecular sieve
	3	NA	5.0	8/26-28/81	2880	$1.44 \times 10^4$	particulate filter and molecular sieve
	Combined 1,2,&3 Streams	NA	1.2	8/26-28/81	2880	$3.46 \times 10^3$	oxidizer furnace and molecular sieve
Environmental Off-Site <sup>c</sup>	-	NA	1.0	8/25-28/81	4230	$3.60 \times 10^3$	molecular sieve

<sup>a</sup> Sample volume adjusted for decreased flow rate during sampling period.

<sup>b</sup> Refer to Figure 7.

<sup>c</sup> Refer to Figure 13.

TABLE 2

## RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL AND WATER

Media and Location <sup>a</sup>	Radionuclide			
	Ra-226	Cs-137	Sr-90	H-3
Soil	Concentration (pCi/g)			
1	0.74 ± 0.14 <sup>b</sup>	0.35 ± 0.08	---	<0.36
2	0.44 ± 0.07	0.21 ± 0.05	---	0.58 ± 0.51
3	0.52 ± 0.11	0.74 ± 0.12	---	---
4	0.56 ± 0.10	0.04 ± 0.05	---	---
5	0.56 ± 0.08	0.21 ± 0.05	0.63 ± 0.21	---
6	<0.05	<0.02	---	<0.36
Water	Concentration (pCi/l or x 10 <sup>-9</sup> µCi/ml)			
1	--- <sup>c</sup>	37 ± 18	---	2330 ± 550
2	---	35 ± 29	---	1170 ± 530
3	0.15 ± 0.15	12 ± 18	1.1 ± 0.6	<250
6	0.10 ± 0.19	<8	---	874 ± 525

<sup>a</sup> Refer to Figure 17.

<sup>b</sup> Error is 2σ based on counting statistics.

<sup>c</sup> Dash indicates analysis not performed.

TABLE 3  
AIR MONITORING RESULTS

Sample Location <sup>a</sup>	Date	Analysis By	Tritium Concentration ( $\mu\text{Ci/ml}$ )		
			Particulate	Aqueous	Gaseous
Stack	8/25-26/82	ORAU	$1.96 \pm 0.01 \times 10^{-9b}$	$3.22 \pm 0.07 \times 10^{-8}$	$1.90 \pm 0.10 \times 10^{-8}$
			1.49 $\times 10^{-9}$	4.06 $\times 10^{-6}$	4.62 $\times 10^{-6}$
Stack	8/26-27/82	ORAU	$1.26 \pm 0.01 \times 10^{-9}$	$2.21 \pm 0.05 \times 10^{-8}$	$4.45 \pm 0.40 \times 10^{-9}$
			1.40 $\times 10^{-9}$	4.30 $\times 10^{-6}$	5.48 $\times 10^{-6}$
Stack	8/27-28/82	ORAU	$7.50 \pm 0.01 \times 10^{-10}$	$6.28 \pm 0.12 \times 10^{-7}$	$2.04 \pm 0.10 \times 10^{-8}$
			1.40 $\times 10^{-9}$	5.64 $\times 10^{-6}$	4.66 $\times 10^{-6}$
Environmental					
1	8/26-28/82	ORAU	$<4.9 \times 10^{-13}$	$1.2 \pm 0.6 \times 10^{-12}$	$4.1 \pm 0.1 \times 10^{-10}$
2	8/26-28/82	ORAU	$<4.9 \times 10^{-13}$	$1.0 \pm 0.7 \times 10^{-12}$	average of three locations
3	8/26-28/82	ORAU	$<4.9 \times 10^{-13}$	$1.3 \pm 0.8 \times 10^{-12}$	
Off-Site	8/25-28/82	ORAU	---	$<5.1 \times 10^{-12}$	---
	8/21-28/82	SLC	---	3.2 $\times 10^{-10}$	---
NRC Guideline Level for Unrestricted Areas <sup>1</sup>			2 $\times 10^{-7}$	2 $\times 10^{-7}$	4 $\times 10^{-5}$

<sup>a</sup> Refer to Figure 7.

<sup>b</sup> Error is  $2\sigma$  based on counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.

NOTE: 1. Due to leakage in the ORAU stack sampling system, ORAU results for aqueous and gaseous tritium in the stack should be considered incorrect.

2. In early 1982 a recalibration of SLC instrumentation indicated that results reported for aqueous tritium during the time of the ORAU survey are high by a factor of approximately 33%.

TABLE 4

## RADIONUCLIDE CONCENTRATIONS IN ON-SITE SURFACE WATER

Location <sup>a</sup>	Radionuclide Concentration (μCi/ml)			
	Ra-226	Cs-137	Sr-90	H-3
W1-Hold-up Tank (ORAU) (SLC)	--- <sup>b</sup> ---	---	---	4.1 ± 0.1 x 10 <sup>-2</sup> 3.7 x 10 <sup>-2</sup>
W2-Drainage Ditch	3.3 ± 1.8 x 10 <sup>-10</sup>	<8 x 10 <sup>-9</sup>	6.4 ± 2.0 x 10 <sup>-9</sup>	6.1 ± 3.7 x 10 <sup>-7</sup>
W3-East Lagoon	3.0 ± 1.8 x 10 <sup>-10</sup>	<8 x 10 <sup>-9</sup>	---	7.14 ± 0.49 x 10 <sup>-6</sup>
NRC Guidline (10CFR20) for unrestricted areas	3 x 10 <sup>-8</sup>	2 x 10 <sup>-5</sup>	3 x 10 <sup>-7</sup>	3 x 10 <sup>-3</sup>
EPA Drinking Water (40CFR141) levels	5 x 10 <sup>-9</sup> (Ra-226 + Ra-228)	1.6 x 10 <sup>-7</sup>	8 x 10 <sup>-9</sup>	2 x 10 <sup>-5</sup>

<sup>a</sup> Refer to Figure 12.

<sup>b</sup> Dash indicates analysis not performed.

<sup>c</sup> Error is 2σ based on counting statistics only.



TABLE 5

## RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE WATER

Sample Location <sup>a</sup>	Radionuclide Concentration (pCi/l or $\times 10^{-9}$ $\mu$ Ci/ml)				Water Depth (m)		
	Ra-226	Cs-137	Sr-90	H-3			
Monitoring Well 1	<0.10	15 $\pm$ 14 <sup>b</sup>	62100 $\pm$ 300	7140 $\pm$ 490	2.1	478	471.2
" " 2	--- <sup>c</sup>	<8	---	5100 $\pm$ 470	0.6	455	466
" " 3	0.08 $\pm$ 0.17	<8	2130 $\pm$ 100	6120 $\pm$ 470	1.5	463	458
" " 4	<0.07	32 $\pm$ 14	477 $\pm$ 30	13500 $\pm$ 600	0.9	455	472
" " 5	9.1 $\pm$ 0.6	<8	3.4 $\pm$ 3.0	4690 $\pm$ 450	0.9	467	464
" " 6	---	<8	---	4490 $\pm$ 450	1.2	455	462
" " 7	---	<8	91 $\pm$ 3	5920 $\pm$ 500	2.1	452	457
" " 8	0.20 $\pm$ 0.19	<8	---	3470 $\pm$ 430	0.6	469	467
" " 9	0.25 $\pm$ 0.20	<8	---	11000 $\pm$ 500	4.4	473	469
" " 10	<0.07	<8	---	6120 $\pm$ 470	1.2	470	466
" " 11	---	<8	---	---	4.4	484	470
" " 12	<0.07	21 $\pm$ 18	---	3670 $\pm$ 430	4.4	462	468
" " 13	0.15 $\pm$ 0.21	57 $\pm$ 18	---	6530 $\pm$ 480	4.2	482	468
" " 14	0.28 $\pm$ 0.20	<8	---	5920 $\pm$ 470	5.0	453	466
" " 15	0.24 $\pm$ 0.20	<8	---	820 $\pm$ 380	7.7	496	471
" " 16	---	<8	---	1020 $\pm$ 380	7.1	451	468
" " 17	---	<8	---	3270 $\pm$ 420	5.5	463	465
" " 18	---	<8	---	3670 $\pm$ 430	1.2	467	463
" " 19	<0.07	<8	142 $\pm$ 40	8980 $\pm$ 520	3.2	468	458
" " 20	<0.07	<8	---	18800 $\pm$ 600	1.4	467	462
" " 21	0.36 $\pm$ 0.23	<8	---	72200 $\pm$ 1100	2.7	475	466
" " 22	d	d	d	20600 $\pm$ 700	3.0	476	466
" " 23	0.16 $\pm$ 0.18	<8	---	9180 $\pm$ 520	3.2	460	470
Borehole " 06	0.25 $\pm$ 0.20	<8	---	6530 $\pm$ 480	4.2	476	462-?
" " 09	<0.10	<8	---	6120 $\pm$ 470	4.2	481	467
NRC Guideline for unrestricted areas <sup>1</sup>	30	20,000	300	3,000,000			
EPA Drinking water level <sup>2</sup>	5 (Ra-226 + Ra-228)	160	8	20,000			

<sup>a</sup> Refer to Figures 3 and 11.

<sup>b</sup> Error is 2 $\sigma$  based on counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.

<sup>d</sup> Insufficient sample.

TABLE 6  
RADIONUCLIDE CONCENTRATIONS IN ON-SITE SURFACE SOIL

Location <sup>a</sup>	Radionuclide Concentrations (pCi/g)		
	Ra-226	Cs-137	Sr-90
1	0.26 ± 0.06 <sup>b</sup>	0.30 ± 0.04	--- <sup>c</sup>
2	0.61 ± 0.09	0.69 ± 0.07	---
3	0.53 ± 0.09	1.06 ± 0.08	---
4	2.34 ± 0.14	0.92 ± 0.08	---
5	0.71 ± 0.10	0.77 ± 0.07	---
6	0.92 ± 0.10	1.77 ± 0.10	---
7	0.59 ± 0.08	0.17 ± 0.04	---
8	4.17 ± 0.18	1.02 ± 0.10	---
9	0.71 ± 0.11	2.28 ± 0.11	---
10	2.12 ± 0.45	304 ± 1	4.68 ± 0.42
11	1.19 ± 0.19	14.8 ± 0.3	5.31 ± 0.37
12	0.49 ± 0.07	0.25 ± 0.06	---
13	0.63 ± 0.11	0.83 ± 0.09	---
14	0.58 ± 0.09	0.83 ± 0.08	---
15	0.83 ± 0.13	1.34 ± 0.10	---
16	2.99 ± 0.17	1.95 ± 0.12	---
17	0.73 ± 0.10	0.13 ± 0.06	---
18	0.70 ± 0.09	0.18 ± 0.05	---
19	0.58 ± 0.09	0.12 ± 0.06	---
20	1.71 ± 0.16	1.22 ± 0.11	---
21	1.03 ± 0.12	0.37 ± 0.06	---
22	1.21 ± 0.15	11.8 ± 0.3	11.7 ± 2.1
23	0.58 ± 0.07	0.76 ± 0.08	---
24	0.95 ± 0.12	1.68 ± 0.11	---
25	2.06 ± 0.15	3.01 ± 0.14	---
26	1.34 ± 0.16	19.5 ± 0.3	6.85 ± 0.68
27	0.78 ± 0.12	3.81 ± 0.17	---
28	0.93 ± 0.15	10.9 ± 0.3	---
29	5.78 ± 0.22	1.33 ± 0.11	---
30	0.60 ± 0.09	0.03 ± 0.04	---
31	0.67 ± 0.10	0.03 ± 0.07	1.50 ± 0.32
32	0.81 ± 0.12	<0.02	---
33	0.86 ± 0.10	1.24 ± 0.09	---
34	0.63 ± 0.09	0.19 ± 0.06	---
35	0.66 ± 0.10	0.41 ± 0.07	10.3 ± 0.4
36	0.61 ± 0.09	0.16 ± 0.06	---
37	0.66 ± 0.11	0.19 ± 0.06	---
38	0.76 ± 0.13	0.34 ± 0.07	0.12 ± 0.21
39	1.29 ± 0.10	0.06 ± 0.05	---
40 <sup>Bd</sup>	67.1 ± 0.9	2.77 ± 0.28	---

Table 6, cont.

## RADIONUCLIDE CONCENTRATIONS IN ON-SITE SURFACE SOIL

Location <sup>a</sup>	Radionuclide Concentrations (pCi/g)		
	Ra-226	Cs-137	Sr-90
41B	220 ± 1	4.79 ± 0.36	---
42B	0.86 ± 0.03	3.28 ± 0.14	---
43B	353 ± 2	8.2 ± 0.5	0.64 ± 0.28
44B	11.8 ± 0.4	21.6 ± 0.4	4.3 ± 0.6
45B	672 ± 9	227 ± 1	1.2 ± 0.3
46B	22.0 ± 0.8	631 ± 2	15.4 ± 0.4

<sup>a</sup> Refer to Figure 10.

<sup>b</sup> Error is 2σ from counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.

<sup>d</sup> Locations with B are "biased" samples.

TABLE 7  
RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE SOIL

Location <sup>a</sup>	Depth (m)	Radionuclide Concentration (pCi/g)			
		Ra-226	Cs-137	Sr-90	H-3
1	1	0.46 ± 0.08 <sup>b</sup>	0.09 ± 0.03	--- <sup>c</sup>	---
2	1	0.43 ± 0.06	0.09 ± 0.03	---	---
	1.5	0.35 ± 0.06	<0.02	---	---
3	0.3	0.54 ± 0.08	0.23 ± 0.05	---	---
	1	0.47 ± 0.06	0.14 ± 0.04	---	---
4	0.3	1.6 ± 0.1	0.41 ± 0.07	---	1.7 ± 0.3
5	1	0.40 ± 0.06	<0.02	---	---
6	1	0.84 ± 0.08	0.08 ± 0.04	0.56 ± 0.23	---
	2	0.73 ± 0.07	0.07 ± 0.02	---	---
	3	0.55 ± 0.08	0.04 ± 0.03	1.6 ± 0.6	---
7	1	0.59 ± 0.08	0.05 ± 0.03	<0.08	---
	2	0.62 ± 0.08	0.03 ± 0.03	---	---
8	1	2.5 ± 0.2	<0.02	---	---
	1.5	1.7 ± 0.1	1.1 ± 0.1	---	---
	2.3	1.6 ± 0.1	0.09 ± 0.06	0.56 ± 0.37	1.0 ± 0.3
9	1	0.54 ± 0.07	0.08 ± 0.04	---	---
	2	0.46 ± 0.07	0.03 ± 0.03	---	---
	2.7	0.29 ± 0.06	0.03 ± 0.03	---	3.1 ± 0.3
	3.6	0.39 ± 0.07	0.03 ± 0.03	1.5 ± 0.3	---
10	0.3	1.9 ± 0.4	286 ± 1	---	---
11	0.3	0.93 ± 0.13	3.1 ± 0.2	---	---
	0.9	0.58 ± 0.09	1.7 ± 0.1	---	---
	1.2	0.64 ± 0.09	0.71 ± 0.09	---	---
12	0.3	0.54 ± 0.08	0.96 ± 0.08	---	---
	1	0.56 ± 0.09	0.06 ± 0.05	---	---
13	0.3	0.60 ± 0.12	1.7 ± 0.1	---	---
	1	0.54 ± 0.09	0.15 ± 0.06	---	---
14	0.3	0.82 ± 0.10	0.44 ± 0.06	---	---
	1	0.93 ± 0.10	1.4 ± 0.1	---	---

TABLE 7, cont.

## RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE SOIL

Location	Depth (m)	Radionuclide Concentration (pCi/g)			
		Ra-226	Cs-137	Sr-90	H-3
15	0.3	0.87 $\pm$ 0.09	2.1 $\pm$ 0.1	---	---
	1	0.59 $\pm$ 0.08	0.11 $\pm$ 0.04	---	---
16	0.3	3.8 $\pm$ 0.2	2.5 $\pm$ 0.1	0.82 $\pm$ 0.21	---
	1	19.8 $\pm$ 0.5	21.7 $\pm$ 0.04	---	---
17	0.3	0.60 $\pm$ 0.09	0.97 $\pm$ 0.08	---	---
	1	0.68 $\pm$ 0.09	0.20 $\pm$ 0.05	---	---
18	0.3	0.91 $\pm$ 0.12	0.63 $\pm$ 0.08	---	---
	1	18.9 $\pm$ 0.4	44.0 $\pm$ 0.5	0.56 $\pm$ 0.22	---
19	0.3	0.79 $\pm$ 0.10	1.1 $\pm$ 0.1	---	---
	1	1.2 $\pm$ 0.1	0.77 $\pm$ 0.08	---	---
20	0.3	1.5 $\pm$ 0.1	0.74 $\pm$ 0.09	---	---
	0.6	1.5 $\pm$ 0.1	0.75 $\pm$ 0.08	---	---
21	0.3	4.6 $\pm$ 0.2	6.5 $\pm$ 0.2	1.3 $\pm$ 0.2	---
	1	1.8 $\pm$ 0.1	2.7 $\pm$ 0.1	---	---
22	0.3	7.1 $\pm$ 0.3	10.0 $\pm$ 0.3	---	---
	1	3.5 $\pm$ 0.2	2.0 $\pm$ 0.1	13.3 $\pm$ 0.7	---
23	0.3	0.89 $\pm$ 0.13	0.40 $\pm$ 0.07	0.17 $\pm$ 0.17	---
	1	0.67 $\pm$ 0.08	0.07 $\pm$ 0.05	---	---
24	0.3	0.74 $\pm$ 0.10	0.26 $\pm$ 0.06	0.67 $\pm$ 0.30	---
	0.8	1.9 $\pm$ 0.2	1.6 $\pm$ 0.1	---	---
25	0.3	0.87 $\pm$ 0.10	0.55 $\pm$ 0.07	---	---
	0.8	0.86 $\pm$ 0.09	0.36 $\pm$ 0.05	---	---
	1	0.86 $\pm$ 0.12	0.97 $\pm$ 0.08	0.93 $\pm$ 0.32	---
26	0.3	0.60 $\pm$ 0.09	0.18 $\pm$ 0.05	---	---
	1	0.66 $\pm$ 0.09	0.19 $\pm$ 0.06	---	---

TABLE 7, cont.

## RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE SOIL

Location	Depth (m)	Radionuclide Concentration (pCi/g)			
		Ra-226	Cs-137	Sr-90	H-3
27	0.3	$0.60 \pm 0.08$	$1.0 \pm 0.1$	---	---
	1	$0.66 \pm 0.09$	$0.19 \pm 0.06$	---	---
28	0.3	$0.81 \pm 0.11$	$13.7 \pm 0.2$	---	---
	0.8	$0.81 \pm 0.11$	$8.3 \pm 0.2$	---	---
29	0.3	$4.1 \pm 0.2$	$0.49 \pm 0.08$	$0.74 \pm 0.21$	---

<sup>a</sup> Refer to Figure 11.

<sup>b</sup> Error is 2 $\sigma$  based on counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.

TABLE 8  
RADIONUCLIDE CONCENTRATIONS IN VEGETATION

Sample Location <sup>a</sup>	Radionuclide Concentration (pCi/g wet wt.)		
	Ra-226	Cs-137	H-3
On-Site: V1	0.23 ± 0.09 <sup>b</sup>	0.05 ± 0.03	25.8 ± 1.9
V2	0.16 ± 0.09	0.71 ± 0.09	76 ± 5
V3	0.08 ± 0.06	0.75 ± 0.07	8.82 ± 1.61
V4	0.07 ± 0.07	0.05 ± 0.03	17.7 ± 1.8
V5	0.10 ± 0.08	2.78 ± 0.17	53.9 ± 2.3
V6	<0.03	0.06 ± 0.04	424 ± 5
Off-Site: V7 Island	0.08 ± 0.04	0.03 ± 0.02	7.35 ± 1.61
V8 Island	0.07 ± 0.05	0.03 ± 0.03	4.41 ± 1.54
Off-Site: V9 Vegetables	<0.03	<0.03	16.9 ± 1.3
V10 Vegetables	<0.03	<0.03	9.7 ± 1.2
V11 Vegetables	<0.03	<0.03	1.22 ± 0.95
V12 Vegetables	<0.03	<0.03	13.6 ± 1.2
Aquatic Vegetation:			
V13 Upstream	0.17 ± 0.06	0.15 ± 0.04	2.21 ± 1.51
V14 SLC Outfall	0.10 ± 0.05	0.06 ± 0.04	21.4 ± 1.82

<sup>a</sup> Refer to Figures 12 and 13.

<sup>b</sup> Error is 2σ based on counting statistics only.

TABLE 9  
RADIONUCLIDE CONCENTRATIONS IN OFF-SITE SURFACE SOIL

Location <sup>a</sup>	Radionuclide Concentration (pCi/g)		
	Ra-226	Cs-137	Sr-90
47	0.55 ± 0.09 <sup>b</sup>	0.11 ± 0.05	--- <sup>c</sup>
48	0.68 ± 0.11	0.16 ± 0.05	---
49	0.77 ± 0.10	0.28 ± 0.08	---
50	0.63 ± 0.11	0.37 ± 0.07	---
51	0.60 ± 0.10	0.19 ± 0.07	---
52	0.84 ± 0.10	0.16 ± 0.07	---
53	0.51 ± 0.11	0.20 ± 0.05	1.88 ± 0.24
54	0.77 ± 0.11	1.08 ± 0.10	---
55	0.71 ± 0.09	0.70 ± 0.07	---
56	0.60 ± 0.09	0.05 ± 0.06	---
57	0.32 ± 0.07	0.36 ± 0.07	---
58	0.73 ± 0.12	0.70 ± 0.08	---
59	0.71 ± 0.12	1.02 ± 0.10	---
60	0.66 ± 0.09	1.06 ± 0.09	---
61	0.39 ± 0.08	0.23 ± 0.04	---
62	0.75 ± 0.09	0.30 ± 0.07	---
63	0.29 ± 0.09	0.16 ± 0.05	---
64	0.66 ± 0.09	1.12 ± 0.09	---

<sup>a</sup> Refer to Figure 15.

<sup>b</sup> Error is 2σ based on counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.



TABLE 10  
RADIONUCLIDE CONCENTRATIONS IN OFF-SITE WATER

Location <sup>a</sup>	Radionuclide Concentration (pCi/l or $\times 10^{-9}$ $\mu$ Ci/ml)			
	Ra-226	Cs-137	Sr-90	H-3
W4-R. Johns Well	$0.22 \pm 0.17^b$	$16 \pm 13$	$1.27 \pm 0.71$	<250
W5-B. Johns Well	<0.10	<8	$0.77 \pm 0.76$	$1630 \pm 390$
W6-Murphy Well	<0.10	<8	<0.31	$1630 \pm 390$
W7-Folk Nursery Well	<0.10	$26 \pm 23$	<0.31	<250
W8-Marr Pond	$0.11 \pm 0.18$	<8	<0.31	$410 \pm 370$
W9-City Water	<0.10	<8	<0.31	$610 \pm 370$
River:				
W10-2 km upstream	--- <sup>c</sup>	<8	---	<250
W11-outfall	---	$13 \pm 11$	---	<250
W12-100 m downstream	<0.10	<8	---	<250
W13-500 m downstream	$0.27 \pm 0.19$	<8	---	<250
W14-2 km downstream	---	$16 \pm 15$	---	<250
NRC Guideline for unrestricted areas <sup>1</sup>	30	20,000	300	3,000,000
EPA Drinking water level <sup>2</sup>	5 (Ra-226 + Ra-228)	160	8	20,000

<sup>a</sup> Refer to Figure 14.

<sup>b</sup> Error is 2 $\sigma$  based on counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.

TABLE 11  
RADIONUCLIDE CONCENTRATIONS IN RIVER SEDIMENT

Location <sup>a</sup>	Radionuclide Concentration (pCi/g)			
	Ra-226	Cs-137	Sr-90	H-3
Upstream 2 km				
R1	0.37 ± 0.06 <sup>b</sup>	0.06 ± 0.03	--- <sup>c</sup>	<0.36
R2	0.35 ± 0.04	0.13 ± 0.03	0.17 ± 0.21	<0.36
R3	0.53 ± 0.11	<0.02	---	<0.36
Near Outfall				
R4	0.45 ± 0.05	0.40 ± 0.04	1.69 ± 0.40	0.45 ± 0.50
Downstream:				
R5-100 m plant side	0.34 ± 0.06	0.16 ± 0.04	0.24 ± 0.21	<0.36
R6-100 m opposite side	0.48 ± 0.06	0.12 ± 0.04	---	<0.36
R7-500 m plant side	0.35 ± 0.05	0.06 ± 0.02	0.21 ± 0.26	0.55 ± 0.53
R8-500 m center	0.35 ± 0.05	0.13 ± 0.03	---	<0.36
R9-500 m opposite side	0.37 ± 0.06	0.11 ± 0.03	---	<0.36
R10-2 km plant side	0.28 ± 0.06	0.06 ± 0.02	---	--- <sup>c</sup>

<sup>a</sup> Refer to Figure 16.

<sup>b</sup> Error is 2σ based on counting statistics only.

<sup>c</sup> Dash indicates analysis not performed.

TABLE 12

RADIONUCLIDE CONCENTRATIONS IN AQUATIC ORGANISMS  
FROM THE SUSQUEHANNA RIVER

Organism and Location	Radionuclide Concentration (pCi/g)		
	Ra-226	Cs-137	H-3
Invertebrates - 1 km upstream	<2.5 *	<1.5 *	---
Invertebrates - facility area	<0.15 *	<0.09 *	---
Juvenile fish - 1 km upstream	<0.03	<0.02	<0.45
Juvenile fish - facility area	<0.05	<0.03	<0.45
Adult fish - 1 km upstream	<0.04	<0.03	<0.45
Adult fish - facility area	<0.05	<0.03	<0.45

\* High minimum detectable activity is the result of small sample size.

#### REFERENCES

1. Title 10, Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, 1981.
2. Title 40, Code of Federal Regulations, Part 141, Interim Primary Drinking Water Regulations. Invitation for Comment. Federal Register, July 1976.
3. Title 40, Code of Federal Regulations, Part 60, Standards of Performance for New Stationary Sources, 1977.

**APPENDIX A**

**MAJOR SAMPLING AND ANALYTICAL EQUIPMENT**

## APPENDIX A

### Major Sampling and Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employers.

#### A. Direct Radiation Measurements

Eberline "RASCAL"  
Portable Ratemeter-Scaler  
Model PRS-1  
Gamma Probe, Model HP-270  
(Eberline Instrument, Santa Fe, NM)

Victoreen THYAC III  
Portable Ratemeter  
Model 490  
Scintillation Probe, Model 489-55  
(Victoreen, Inc., Cleveland, OH)

Pressurized Ionization Chamber (PIC)  
Model RSS-111  
(Reuter-Stokes, Cleveland, OH)

#### B. Air Sampling

Aluminum In-Line Filter Holders  
47 mm  
Cat. #996209  
(Research Appliance Co., Cambridge, MD)

Stack Sampling Nozzles  
(NuTech Corp., Durham NC)

Rotameters  
(Union Carbide Corp., Linde Air Products Div.,  
Birmingham, AL)

Membrane Particulate Filters  
Metrical, 47 mm diam., 0.8  $\mu$ m pore size  
(Gelman Sciences, Inc., Ann Arbor, MI)

Molecular Sieve  
Type 4A, 14 x 30 Mesh  
(Linde Division, Union Carbide Corp., South Plainfield, NJ)

Oxidizer Furnace  
30 watts/in. Serial #B-73494  
(Industrial Heater, New York, NY)

Palladium Sponge (10 g/furnace)  
(Englehard Chemicals, Newark, NJ)

Gast Vacuum Pump  
115v/60Hz  
Cat. #P8400  
(American Scientific Products, Stone Mountain, GA)

Velometer - all purpose set  
Type 6000 a.p.  
(Alnor Instrument Co., Niles, NJ)

"Precision" Wet Test Meter  
Used to calibrate rotameters  
(Precision Scientific Co., Chicago, IL)

Meteorological Monitoring System  
Model R-400  
(Texas Electronics, Inc., Dallas, TX)

Additional supplies  
Plastic tubing, miscellaneous connectors

C. Laboratory Analysis

Ge(Li) Detector  
Model LGCC2220SD, 23% efficiency  
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:  
Lead Shield, SPG-16  
(Applied Physical Technology, Smyrna, GA)

Pulse Height Analyzer, ND66  
Model 88-0629  
(Nuclear Data, Inc., Schaumburg, IL)

Alpha Spectroscopy System  
Tracor Northern 1705  
Pulcir PA-1 Alpha Module  
(Pulcir, Inc., Oak Ridge, TN)

Low Background Alpha-Beta Counter  
Model LB5100-2080  
(Tennelec, Inc., Oak Ridge, TN)

Liquid Scintillation Counter  
Model A300C  
(Packard Instrument Co., Downers Grove, IL)

**APPENDIX B**  
**ANALYTICAL PROCEDURES**



## APPENDIX B

### Analytical Procedures

#### Gamma Exposure Rate Measurements

Measurements of gamma exposure rates were performed using a Victoreen Thyac III Model 490 portable ratemeter with a Victoreen Model 489-55 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. Count rates (cpm) were converted to exposure levels ( $\mu\text{R/h}$ ) using a factor of  $450 \text{ cpm} \approx 1 \mu\text{R/h}$ . This factor was determined by comparing the response of the scintillation detector to gamma photons from Ra-226 with that of a Reuter Stokes model RSS-111 pressurized ionization chamber.

#### Beta-Gamma Surface Measurements

Measurements were performed using Eberline "Rascal," Model PRS-1, portable ratemeters with Model HP-270 energy compensated G-M probes. Since no significant difference was noted between counting rates in the open- and closed-shield configurations, the gamma exposure levels determined above were considered representative of the direct surface radiation and calculations of dose rates were not performed.

#### Soil and Sediment

##### Gamma Spectrometry

Soil and sediment samples were dried at  $120^{\circ}\text{C}$ , finely ground, mixed, and a portion placed in a one-liter Marinelli beaker for gamma spectrometry. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and ranged from 400 to 600 g. A 23% Ge(Li) detector (Princeton Gamma-Tech) coupled to a Nuclear Data Model ND66 pulse height analyzer was used for analysis. Photopeak search and identification was provided by a computerized peak-search

program. Where a photopeak was identified, the Compton continuum was subtracted and appropriate calibration and correction factors applied. Energies used for radionuclide identification were as follows:

Radium-226: 609 keV from Bi-214

Cesium-137: 662 keV

#### Strontium-90

Selected soil samples were analyzed for Sr-90 using radiochemical procedures described in Attachment 1.

#### Tritium

Approximately 50 g of undried soil was placed in a distillation flask and 100 ml of distilled water added. The mixture was refluxed for one hour and then distilled. An 8 ml aliquot of the distillate was placed in 14 ml of scintillation cocktail (Insta-Gel by Packard) and analyzed in a Packard liquid scintillation spectrometer.

#### Water Samples

Approximately 100 ml of each sample was immediately transferred to separate glass bottles and retained for tritium analysis. The remainder of the sample was filtered through 0.45  $\mu$ m pore size membrane filters.

#### Gamma Spectrometry

Five hundred milliliters of filtered samples were placed in one-liter Marinelli beakers and analyzed by Ge(Li) gamma spectrometry using the same techniques as for soil samples.

## Tritium

The sample was distilled and 8 ml of the distillate mixed with 14 ml of Insta-Gel scintillation "cocktail." Analysis was performed using a liquid scintillation spectrometer.

## Strontium-90

Selected samples were analyzed for Sr-90 using the procedure described in Attachment 2.

## Radium-226 - Emanation Method

Selected samples were analyzed for Ra-226 using the standard radon emanation technique EPA 600/4-75-008 (Revised).

## Air Samples

Filter papers were placed directly into liquid scintillation cocktails and analyzed in a Packard liquid scintillation spectrometer. Molecular sieve was placed in a distillation flask, 20 ml of low-tritium water added, and the mixture heated to 375° C. Nitrogen was used as a carrier gas for the process. An 8 ml aliquot of the distillate was analyzed by liquid scintillation spectrometry. Due to the high moisture content of the stack discharge, those molecular sieve traps became saturated, preventing determination of the sieve collection efficiency. The tritium concentration of the moisture on the trap was assumed to be representative of the average tritium concentration in the stack discharge during the sampling period. The other molecular sieve air samples did not experience the heavy moisture loading.

### Calibration and Quality Assurance

Laboratory instruments are calibrated using NBS-tracable standards. Portable survey equipment for exposure rate measurement is calibrated by comparing its response with that of a pressurized ionization chamber having NBS-certified calibration provided by the supplier.

Quality control procedures include daily background and source measurements to confirm lack of malfunctions and nonstatistical deviations. The ORAU laboratory participates in the EPA Quality Assurance Program.

## Vegetation

### Gamma Spectrometry

Vegetation samples were air dried, chopped, mixed, and 200-250 g placed in a 3.5 l Marinelli beaker for gamma spectrometry (see procedure for soil described above).

### Tritium

Approximately 50 g of undried vegetation was placed in a distillation flask, 100 ml of distilled water added, and the mixture refluxed for approximately one hour. An aliquot of the distillate was analyzed for tritium as described above for soil and liquid.

## Aquatic Organisms (fish, invertebrates)

### Gamma Spectrometry

Fish and invertebrates were chopped into small pieces and placed in one-liter Marinelli beakers for analysis as described above for soil samples.

### Tritium

Approximately 50 g of undried vegetation was placed in a distillation flask, 100 ml of distilled water added, and the mixture refluxed for approximately one hour. An aliquot of the distillate was analyzed for tritium as described above for soil and liquid.

## ATTACHMENT 1

### ANALYSIS OF WATER FOR STRONTIUM 90

1. To 1 liter of water in a two-liter beaker, add 1 ml strontium (20 mg/ml) carrier solution, 1 ml barium (10 mg/l) carrier solution and 5 ml calcium carrier solution. (Improved precipitation may be obtained by adding calcium to soft waters.) If sample has been acidified neutralize with 6N NaOH. Stir well and heat to near boiling on hot plate.
2. Add 30 ml of 3N  $\text{Na}_2\text{CO}_3$  with stirring, then add 1-2 ml of 6N NaOH. Continue heating for approximately one more minute. Remove from hot plate and cool in a water bath.
3. Decant supernate. Transfer the precipitate to a 250-ml centrifuge bottle with distilled water. Centrifuge and discard the supernate.
4. Dissolve the precipitate in 20 ml 6N HCl. Add 200 ml water.
5. If insoluble residue (silica) is present, filter and wash residue once with 200-ml portion of water and add wash solution to filtrate. Discard residue.
6. Add dissolved sample and filtrate to 500 ml of 6% EDTA solution.
7. In a two-liter plastic beaker, adjust the solution to pH 5.8 with approximately 20 ml concentrated  $\text{NH}_4\text{OH}$ .
8. Add 20 ml buffer solution (pH 4.6 ) and adjust to pH 4.6 with 6N HCl or dilute  $\text{NH}_4\text{OH}$ , then dilute to 1 liter.

9. Let the solution flow through the resin column at 20 ml/min. Stop the flow when just enough solution remains to cover the resin.
10. Combine 200 ml 6% EDTA and 400 ml water; adjust to pH 5.1 with 6N  $\text{NH}_4\text{OH}$ , place in reservoir, and let flow at 20 ml/min.
11. Record time at end of elution as beginning of yttrium-90 ingrowth.
12. Wash the column with 200 ml water at a flowrate of 20 ml/min. Discard all the effluents.
13. Place 1000 ml of 4N NaCl in the reservoir and let it flow through the column at 20 ml/min.
14. Collect the first 400 ml of eluate, which contains the strontium and barium. Allow the remaining 600 ml of 4N NaCl to pass through to recharge the resin at 10 ml/min. Wash column with 500 ml of deionized water to remove any remaining NaCl. (NOTE: If the resin appears milky, empty the resin into a 400-ml beaker. Wash the resin back into the resin column to be used again.)
15. Add 1 ml 6N NaOH to the 400 ml of strontium-barium eluate.
16. Stir and slowly add 10 ml of 3N  $\text{Na}_2\text{CO}_3$ . Continue stirring vigorously with a magnetic stirrer for 30 minutes.
17. Transfer half of the solution to a 250-ml centrifuge bottle. Centrifuge and discard the supernate. Add the remaining solution to the precipitate in the 250-ml bottle. Centrifuge again and discard the supernate.

18. Dissolve the precipitate in 5 ml of 1N  $\text{HNO}_3$  and transfer to a 50-ml centrifuge tube.
19. Wash the 250-ml bottle with 5 ml of ammonium acetate buffer (pH 5.2 ) and add the wash to the dissolved precipitate in the 50-ml centrifuge tube.
20. Heat in a boiling water bath, with stirring, for 25 minutes and slowly add 1 ml of 0.5N  $\text{NaCrO}_4$ . Continue to stir for 2-3 minutes. Remove from heat and cool.
21. Centrifuge and decant supernatant liquid containing the strontium into another 50-ml centrifuge tube.  
(NOTE: The precipitate left is considered to be barium chromate -  $\text{BaCrO}_4$ . This precipitate may also be considered as containing all the heavy metals including any radium isotopes. The precipitate may be slurried with water, filtered, and counted for either its radium content (total alpha), gross alpha, or a spectral analysis for its barium-140 content. The percent yield is calculated from the quantity of barium carrier originally added to the sample vs the quantity of barium recovered as  $\text{BaCrO}_4$ .)
22. To the strontium-containing supernate, add 2 ml concentrated  $\text{NH}_4\text{OH}$  and stir slowly.
23. Reprecipitate the strontium as the carbonate by adding 2 ml of 3N  $\text{Na}_2\text{CO}_3$ .
24. Stir for approximately 2-5 minutes. If necessary to precipitate the  $\text{SrCO}_3$ , the sample may be cooled in an ice bath.
25. Centrifuge and discard the supernate. Add 20 ml of distilled water to wash the sample. Centrifuge and discard the supernate.



26. Collect the  $\text{SrCO}_3$  on a tared filter (Whatman 542) and wash with three 10-ml portions each of water and 95% ethanol.
27. Carefully remove the filter to the appropriate planchet for drying, weighing, and counting.
28. Wait approximately 2 hours before counting to allow for drying and radon daughters to decay.
29. Weigh, and count in a Tennelec model LB5100 low-background beta counter.
30. If the first count is not obtained within thirteen hours (i.e., counter jams, power failure, etc.), the sample must be reanalyzed. If the total amount of the sample is very limited or a time factor is involved, repeat the reprecipitation procedure as follows.
  - a. Add filter paper and precipitate to a 40-ml centrifuge tube.
  - b. Add 5 ml concentrated  $\text{HNO}_3$  to redissolve sample. Digest for 10 minutes.
  - c. Remove filter paper from centrifuge tube. Rinse filter with concentrated  $\text{HNO}_3$  from dropping bottle.
  - d. Add 20 ml of fuming  $\text{HNO}_3$ .
  - e. Cool in ice bath for 30 minutes.
  - f. Centrifuge and pour off liquid (fuming nitric acid). Record time (separation time).
  - g. Add approximately 5 ml of water to redissolve the sample.
  - h. Add 5 ml concentrated  $\text{NH}_4\text{OH}$ . While stirring add 4 ml 3N of  $\text{Na}_2\text{CO}_3$ . Stir for 10 minutes.
  - i. Filter on a tared filter. Wash 3 times, once with a 20-ml portion of each: deionized water and ethyl alcohol.
  - j. Weigh as  $\text{SrCO}_3$  count for Sr-89 and Sr-90.

### 31. Calculation of Results

Strontium-89, -90 results are obtained from the appropriate program on the TI59 system using the following equations.

Strontium-90 Calculations:

$$\text{pCi Sr-90/unit} = \frac{[A][B] - [C][D]}{[1+(E)(F)](A) - [1+(E)(G)](C)} \times \frac{1}{(2.22)(H)(I)(J)}$$

A = Decay of Sr-89 from the time of collection to the time of the first count is figured to the nearest one-half day.

B = Net counts per minute of total strontium on second count is figured to the nearest tenth.

C = Decay of Sr-89 from the time of collection to the time of the second count is figured to the nearest one-half day.

D = Net counts per minute of total strontium on first count is figured to the nearest tenth.

E = Ratio of the Y-90/Sr-90 counting efficiencies (including self-absorption corrections).

F = Y-90 ingrowth from the time of separation to the time of second count is figured to the nearest hour.

G = Ingrowth of Y-90 from time of separation to time of first count is figured to the nearest one-half hour.

H = Counting efficiency of Sr-90 (including self-absorption correction).

I = Chemical yield of strontium.

J = Sample volume in liters of sample weight in grams.

A, C, F, G were once found by tables but are now found by the TI59 program since all functions of  $e^{-\gamma t}$  where  $\gamma$  is the decay constant of the nuclide and  $t$  is elapsed time.

E, H, are efficiencies corrected for self-absorption that have been determined by calibration. The equations for the absorption curves are entered in the TI59 program.

Strontium-89 Calculations:

$$\text{pCi Sr-89/unit} = \frac{A - [1+(B)(C)]D}{E} \times \frac{1}{(F)(G)(H)2.22}$$

A = net cpm total strontium on first count.

B = Y-90 ingrowth from time of separation to the time of first count.

C = Ratio of Y-90/Sr-90 counting efficiencies (including self-absorption corrections).

D = Net cpm of Sr-90.

E = Decay of Sr-89 from time of collection to the time of first count.

F = Chemical yield of strontium.

G = Counting efficiency of Sr-90 including self-absorption corrections.

H = Sample volume in liters or sample weight in grams.

## ATTACHMENT 2

### ANALYSIS OF SOIL FOR STRONTIUM 90

1. Weigh a 5 gm aliquot of dried soil.
2. Pipet 1 ml strontium carrier (20 mg/ml) and 1 ml barium carrier (10 mg/ml) into the soil.
3. Add 1 ml of 2N  $\text{Ca}(\text{NO}_3)_2$  solution.
4. Add 15 gm of NaOH pellets.
5. Fuse over a burner for 30 minutes and then slowly stir in 2.5 g of anhydrous  $\text{Na}_2\text{CO}_3$  and heat the clear red melt for 30 minutes. Sometimes it is necessary to add extra NaOH to special samples. (Note: A crucible cover is used during the fusing procedure to prevent loss of sample, should it spatter.)
6. Remove the crucible from the flame to a cold water bath to crack the mixture. Let stand in cold water approximately 20 minutes.
7. Transfer the mixture to a one-liter beaker by boiling approximately 25 ml of distilled water in the nickel crucible, repeat until entire mixture is transferred. Boil on a hot plate until mixture is broken up. Keep volume at 200 ml.
8. Cool in a water bath and then transfer the mixture to a 250-ml centrifuge bottle with distilled water.
9. Centrifuge for 5 minutes and discard the supernate. Wash the precipitate 5 times with 10-15° C distilled water.

10. Add 20 ml of 6N HCl acid to dissolve the mixture. Add 100 ml of cold distilled water to the sample and filter through an E & D No. 513, or equivalent, 32-cm filter into a 500-ml beaker. Wash with two 100-ml portions of hot distilled water. Discard the residue.
11. Add dissolved sample and filtrate to 500 ml 6% EDTA solution. In a two-liter glass beaker, adjust the solution to pH 4.2 or until the solution is clear with 15N  $\text{NH}_4\text{OH}$ , then back to 3.8 with concentrated HCl. (NOTE: pH 3.8 is very important. If pH is less than 3.8, EDTA may precipitate.)
12. Stir the solution vigorously for at least 30 minutes to precipitate the magnesium salt of EDTA. Allow the precipitate to settle overnight.
13. Filter and adjust the filtrate to pH 5.8 with approximately 3 ml 15N  $\text{NH}_4\text{OH}$ . Add 20 ml buffer solution (pH 4.6) and adjust pH to 4.6 with 6N HCl or dilute  $\text{NH}_4\text{OH}$  then dilute to 1 liter. (NOTE: Use E & D No. 513, 32 cm folded paper, or equivalent, to filter the magnesium salt.)
14. Let the solution flow through the resin column at 20 ml/min. Stop the flow when just enough solution remains to cover the resin.
15. Combine 200 ml 6% EDTA and 400 ml water; adjust to pH 5.1 with 6N  $\text{NH}_4\text{OH}$ , place in reservoir, and let flow at 20 ml/min.
16. Record time at end of elution as beginning of yttrium-90 ingrowth.
17. Wash the column with 200 ml water at a flowrate of 20 ml/min. Discard all the effluents.

18. Place 1000 ml of 4N NaCl in the reservoir and let it flow through the column at 20 ml/min.
19. Collect the first 400 ml of eluate, which contains the strontium and barium. Allow the remaining 600 ml of 4N NaCl to pass through to recharge the resin at 10 ml/min. Wash column with 500 ml of deionized water to remove any remaining NaCl.  
(NOTE: If the resin appears milky, empty the resin into a 400-ml beaker. Wash the resin back into the resin column to be used again.)
20. Add 1 ml 6N NaOH to the 400 ml of strontium-barium eluate.
21. Stir and slowly add 10 ml of 3N Na<sub>2</sub>CO<sub>3</sub>. Continue stirring vigorously with a magnetic stirrer for 30 minutes.
22. Transfer half of the solution to a 250-ml centrifuge bottle. Centrifuge and discard the supernate. Add the remaining solution to the precipitate in the 250-ml bottle. Centrifuge again and discard the supernate.
23. Dissolve the precipitate in 5 ml of 1N HNO<sub>3</sub> and transfer to a 50-ml centrifuge tube.
24. Wash the 250-ml bottle with 5 ml of ammonium acetate buffer (pH 5.2 ) and add the wash to the dissolved precipitate in the 50-ml centrifuge tube.
25. Heat in a boiling water bath, with stirring, for 25 minutes and slowly add 1 ml of 0.5N Na<sub>2</sub>CrO<sub>4</sub>. Continue to stir for 2-3 minutes. Remove from heat and cool.
26. Centrifuge and decant supernatant liquid containing the strontium into another 50-ml centrifuge tube.  
(NOTE: The precipitate left is considered to be barium chromate - BaCrO<sub>4</sub>. This precipitate may also be considered as

containing all the heavy metals including any radium isotopes. The precipitate may be slurried with water, filtered, and counted for either its radium content (total alpha), gross alpha, or a spectral analysis for its barium-140 content. The percent yield is calculated from the quantity of barium carrier originally added to the sample vs the quantity of barium recovered as  $\text{BaCrO}_4$ ).

27. To the strontium-containing supernate, add 2 ml concentrated  $\text{NH}_4\text{OH}$  and stir slowly.
28. Reprecipitate the strontium as the carbonate by adding 2 ml of  $3\text{N Na}_2\text{CO}_3$ .
29. Stir for approximately 2-5 minutes. If necessary to precipitate the  $\text{SrCO}_3$ , the sample may be cooled in an ice bath.
30. Centrifuge and discard the supernate. Add 20 ml of distilled water to wash the sample. Centrifuge and discard the supernate.
31. Collect the  $\text{SrCO}_3$  on a tared filter (Whatman 542) and wash with three 10-ml portions each of water and 95% ethanol.
32. Carefully remove the filter to the appropriate planchet for drying, weighting, and counting.
33. Wait approximately 2 hours before counting to allow for drying and radon daughters to decay.
34. Weigh, and count in a Tennelec model LB5100 low-background beta counter.
35. If the first count is not obtained within thirteen hours (i.e., counter jams, power failure, etc.), the sample must be reanalyzed. If the total amount of the sample is very limited or a time factor is involved, repeat the reprecipitation procedure as follows.

- a. Add filter paper and precipitate to a 40-ml centrifuge tube.
- b. Add 5 ml concentrated  $\text{HNO}_3$  to redissolve sample. Digest for 10 minutes.
- c. Remove filter paper from centrifuge tube. Rinse filter with concentrated nitric acid from dropping bottle.
- d. Add 20 ml of fuming  $\text{HNO}_3$ .
- e. Cool in ice bath for 30 minutes.
- f. Centrifuge and pour off liquid (fuming  $\text{HNO}_3$ ). Record time (separation time).
- g. Add approximately 5 ml of water to redissolve the sample.
- h. Add 5 ml concentrated  $\text{NH}_4\text{OH}$ . While stirring add 4 ml  $3\text{N}$   $\text{Na}_2\text{CO}_3$ . Stir for 10 minutes.
- i. Filter on a tared filter. Wash 3 times, once with a 20-ml portion of each: deionized water and ethyl alcohol.
- j. Weigh as  $\text{SrCO}_3$  and count for Sr-89 and Sr-90.

### 36. Calculation of Results

Strontium-89, -90 results are obtained from the appropriate program on the TI59 system using the following equations.

Strontium-90 Calculations:

$$\text{pCi Sr-90/unit} = \frac{[A][B] - [C][D]}{[1+(E)(F)](A) - [1+(E)(G)](C)} \times \frac{1}{(2.22)(H)(I)(J)}$$

A = Decay of Sr-89 from the time of collection to the time of the first count is figured to the nearest one-half day.

B = Net counts per minute of total strontium on second count is figured to the nearest tenth.

C = Decay of Sr-89 from the time of collection to the time of the second count is figured to the nearest one-half day.

D = Net counts per minute of total strontium on first count is figured to the nearest tenth.

E = Ratio of the Y-90/Sr-90 counting efficiencies (including self-absorption corrections).

F = Y-90 ingrowth from the time of separation to the time of second count is figured to the nearest hour.



- G = Ingrowth of Y-90 from time of separation to time of first count is figured to the nearest one-half hour.
- H = Counting efficiency of Sr-90 (including self-absorption correction).
- I = Chemical yield of strontium.
- J = Sample volume in liters of sample weight in grams.

A, C, F, G were once found by tables but are now found by the TI59 program since all functions of  $e^{-\gamma t}$  where  $\gamma$  is the decay constant of the nuclide and t is elapsed time.

E, H, are efficiencies corrected for self-absorption that have been determined by calibration. The equations for the absorption curves are entered in the TI59 program.

Strontium-89 Calculations:

$$\text{pCi Sr-89/unit} = \frac{A - [1 + (B)(C)]D}{E} \times \frac{1}{(F)(G)(H)2.22}$$

- A = net cpm total strontium on first count.
- B = Y-90 ingrowth from time of separation to the time of first count.
- C = Ratio of Y-90/Sr-90 counting efficiencies (including self-absorption corrections).
- D = Net cpm of Sr-90.
- E = Decay of Sr-89 from time of collection to the time of first count.
- F = Chemical yield of strontium.
- G = Counting efficiency of Sr-90 including self-absorption corrections.
- H = Sample volume in liters or sample weight in grams.